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PROCEEDINGS

SECOND MEETING, SECOND HALF, 64TH SESSION

In the Chair: THE PRESIDENT, COLONEL THE MASTER OF SEMPILL

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, January 31st, 1929.

The PRESIDENT: The subject of the paper was one which all interested in aeronautics had been discussing since the beginning, and on which they had so far failed to reach any specific conclusion. He would not predict that as the result of the reading and discussion of the paper a conclusion would be or, in fact, could be reached, but they would certainly get a little nearer to it. The paper linked up very well indeed with the splendid paper read before the Society by Professor Melvill Jones, on the performance of the perfectly streamline aeroplane, at a meeting held on January 10th, and it was unfortunate that Professor Melvill Jones, who had been asked to open the discussion upon Mr. Farren's paper, had been prevented by illness from so doing.

Mr. Farren's experience, continued the President, extended over very many years. He was in charge of the full-scale experimental work at the Royal Aircraft Establishment during the war. In 1917 he became connected with the Advisory Committee for Aeronautics, which subsequently had become the Aeronautical Research Committee, and was to-day serving on six or seven sub-committees of that body. For the past few years he had been assisting Professor Melvill Jones at Cambridge, and was Lecturer in Aeronautics at the University. Further, he gave advice, when called upon, to various commercial organisations, such as the Armstrong-Siddeley Company, and had had something to do with the development of the "Argosy," the latest commercial machine in course of development. He had contributed valuable articles to the Journal and had given two important lectures before the Society.

MONOPLANE OR BIPLANE?

BY W. S. FARREN, M.B.E., M.A., F.R.AE.S., M.I.AE.E.

The Council of the Society has asked me in this lecture to deal with the problem "Monoplane or Biplane?" particularly with reference to the large commercial aeroplane of the future. I hope to be able to show you that, if certain premises which appear to me to be reasonable are conceded, it is probable that for commercial aeroplanes of between 15,000 and 40,000 lbs. in total weight, the biplane arrangement which has been developed mainly in this country has on the whole the advantage. By a "commercial" aeroplane I mean one which may reasonably be expected to pay its way—to "fly by itself" financially—in a part of the world where such phenomena as "waves of prosperity" are as remote from our expectation as in our memories, where we can exist only by practising true economy in every detail of our national life, where subsidies for even so inspiring a means of transport as flight cannot endure indefinitely. From a general survey of such real civil aviation as exists, I can see no early prospect of making such an aeroplane with a cruising speed exceeding 100 m.p.h., and I propose to consider the problem of "Monoplane or Biplane" on this basis.

In one respect the solution of a purely commercial problem is in principle simple. We seek for the combination of characteristics which will produce the best return on the capital involved. Here we have a common factor in terms of which every proposal can be expressed—money.

The items of expenditure with which our problem is concerned may be divided into two classes. First, general commercial expenses:—

(1) Interest on first cost.
(2) Depreciation.
(3) Maintenance and repair.
(4) Insurance.
(5) Housing (as affected by size).

As to the first three I propose to say nothing, leaving it to those who are in a better position to judge to give their views. Insurance rates on certain British commercial aeroplanes are, I believe, lower than on any other aircraft—presumably because they are judged to be safer. I hope to show that they are safer to some extent because they are biplanes. As for housing, it will appear that a biplane is appreciably more compact than the equivalent monoplane.

The above items are difficult to assess mainly because a detailed analysis of the expenditure of Imperial Airways is not available.

Secondly, we have items of a more strictly technical nature:—

(6) Fuel consumption.
(7) Non-paying load.

The first will be seen to be slightly in favour of the monoplane, for the same total weight of aeroplane and the same engine power. It is in respect of the second that the monoplane appears to be at an appreciable disadvantage for a given standard of safety.

If we can establish the position on these last two points quantitatively, we shall at least be able with a clear conscience to hand over the responsibility of a decision to those who have the information on the first five—since they are disinclined to take us into their confidence.

Even supposing we can assess all these factors fairly, there is one which may outweigh them all—the reaction of the man in the street. Will our decision on a matter such as I am to discuss influence him for or against travel by air?

Or will it be a matter of indifference to him? If we may neglect mere "fashion," I think we can frame our problem so that the variations involved may be reasonably expected to be a matter of indifference to the lay public. The crucial test, "Will it pay?" is then applicable. It is my view that the question in my title can be answered only if this condition is carefully observed. For example—a point I shall elaborate later—it is not legitimate to compare directly such aeroplanes as the Argosy and the Junkers G.31, since they are based on different conceptions of fundamental safety, a matter in which I hold the lay public cannot be considered to be uninterested.

There are certain premises which I regard as fundamental. Any discussion of the problem which does not accept them as a basis must in my view be fruitless. Some definite standards of strength, stability and control, take-off, and stalling speed are necessary if a standard of safety is to be maintained. I regard these four, moreover, as independent of one another, with the possible exception that a rise in stalling speed is admissible if really adequate control beyond the stall is provided. What numerical values should be assigned is, of course, a matter for discussion. It will appear that the choice between monoplane and biplane is influenced in particular by the stalling speed selected.

Presuming that these are accepted, we have then to select from several possibilities quantities in terms of which the variation of the characteristics of equivalent monoplanes and biplanes can be expressed. I propose to take as fixed the total weight of the aeroplane, and the range in air miles at a fixed fraction of the maximum engine power. The essential differences between the alternative types (parasite resistance and structure weight) then appear as a difference in cruising speed and paying load.

I have set out in Appendix I., in a form suitable for my purpose, the usual performance relations. It will be seen that from them can be deduced two simple expressions giving, one the ratio of the spans of the equivalent biplane and monoplane, and the other the increase in cruising speed which will follow the change from biplane to monoplane.

The first is briefly an expression of equality of total resistance under take-off conditions and assumes that we start with a biplane whose take-off is the minimum permissible. As will be seen later from examples, it results in the span of the monoplane and biplane being practically equal, the higher induced drag of the former being arranged so as to balance its lower parasite drag. It is possible that a better all-round result would be obtained by a larger span for the monoplane, giving it a better take-off and a still greater gain of cruising speed (owing to the lower induced drag), but I think it will be seen from what follows that in general there would be a rise in structure weight which the monoplane can ill afford.

The next step is to arrive at equivalent dimensions for other essential parts. In Appendix II. I have discussed the problems involved in stability and control, and although there is some scope for difference of opinion on what particular combination of tail length, trail area, and rudder and fin area represents the best compromise, the nett effect on the structure weight can be estimated closely enough for my purpose.

Finally, if we make an allowance for the difference in fuel consequent on the change in cruising speed (at the same b.h.p.), we are in a position to lay out the two alternatives. We may then ponder over the structural problem we have set ourselves and consider what other advantages and disadvantages follow.

Let us take an example. As I happen to be familiar with its details, and as it is a type which apparently meets the requirements of Imperial Airways for certain services, I propose to take the Argosy and to lay out the general proportions of equivalent monoplanes.

According to my estimate, based on the usual data, the resistance of the wing bracing of the Argosy may be expressed approximately in any one of the following ways:—

12 per cent. of the total resistance at cruising speed (90 m.p.h.);
21 per cent. of the parasite resistance of the whole machine;
57 per cent. of the profile resistance of the wings; or
1.8 per cent. of the weight at 100 m.p.h.

Of this, approximately half is in the wires and struts themselves and half in end-fittings and "interference." I have examined a number of biplanes of similar size and I do not think there would be among them any material variation in the first two figures.

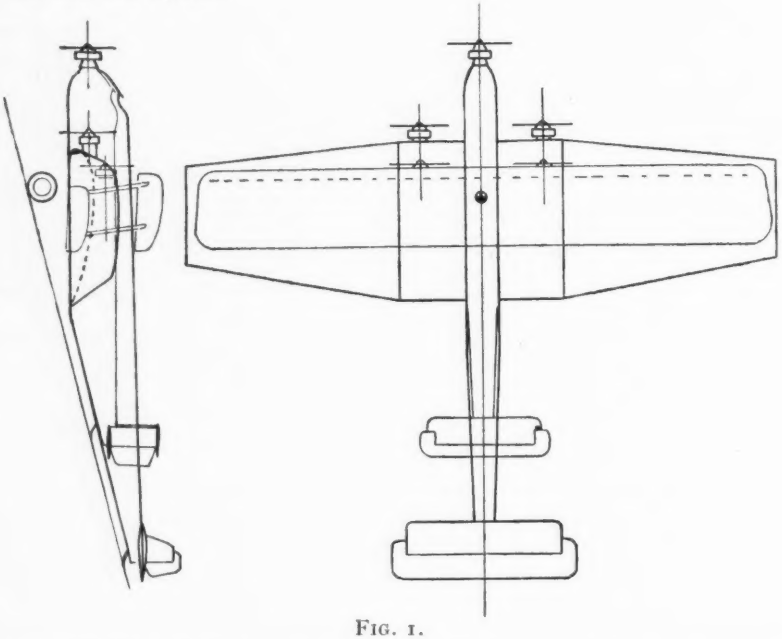

FIG. 1.

During the last three years biplane design has moved in the direction of lower profile resistance (by the use of wings with slightly higher maximum lifts): of lower general parasite resistance, particularly of bodies and engines; and of lower wing bracing resistance (by the use of fewer bays in conjunction with deeper wing sections). The net result is to leave the first two of the four figures given above very much as they were, but to reduce the last two to, say, 50 per cent. and 1.3 per cent. If we could eliminate the bulky end fittings associated with raf-wires, and reduce the "interference" by fairing, we could bring these two down to something of the order of 30 per cent. and 0.8 per cent. The problem of accessibility for maintenance is not one in which a competent designer should see insuperable difficulties. The last figures are in the nature of an irreducible minimum—the tax which a biplane pays for being a biplane. Most biplanes pay more.

Figs. 1, 2 and 3 show superposed, the outline of the Argosy and three equivalent monoplanes. The corresponding dimensions are given in Table I.[1]

[1] For details of the basis on which these have been decided, see Appendix I. and II.

TABLE I.

COMPARISON OF BIPLANE AND MONOPLANES.

(i) DIMENSIONS, ETC.

Type.	Biplane (Argosy).	Monoplane A.	Monoplane B.	Monoplane C.	Remarks.
Wing area S	1900	1900	1500	1500	
K_L	0.55	0.55	0.70	0.70	
k_{Do}	0.006	0.006	0.006	0.0076	
Profile R_o/W	0.0313	0.0313	0.0249	0.0313	At 100 m.p.h.
Parasite R_p/W	0.0830	0.0651	0.0651	0.0651	
Induced R_i/W	0.0224	0.0280	0.0300	0.0280	
Span B	89.5	91	87.5	91	See Appendix I.
Mean chord C	11.1	20.7	16.9	16.2	
$\tau = l/C$	3.34	2.5	2.75	2.75	See Appendix II.
$a = S'/S$	0.114	0.129	0.112	0.108	
Tail volume (ar)	0.380	0.323	0.309	0.297	
Tail area S'	215	242	166	160	
Rudder + fin area S''	118	86	96	102	
Gain in cruising speed $\delta V_o/V_o$ ...	—	0.039	0.051	0.039	See Appendix I.

The first (A, Fig. 1) assumes that the maximum lift coefficient is the same for both monoplane and biplane. We have evidence (Aeronautical Research Committee R. & M. 945) that the maximum lift coefficient developed by the Junkers

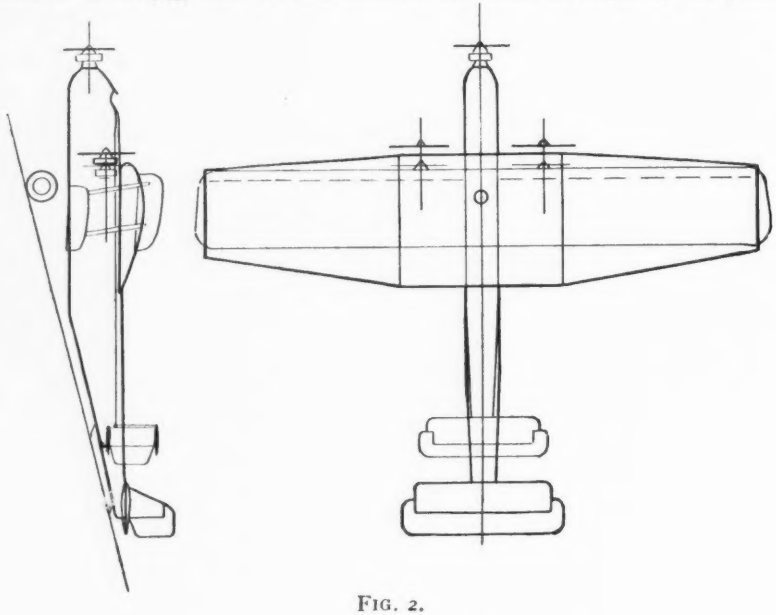

FIG. 2.

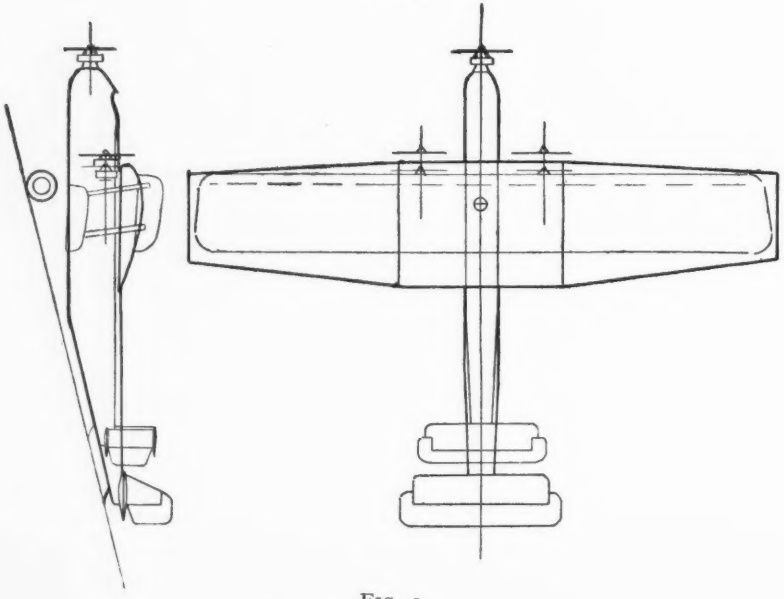

FIG. 3.

J.13 does not exceed 0.55, and there seems no reason to expect a different result in the larger machines.

The second (B, Fig. 2) assumes $K_L=0.55$ for the biplane and 0.70 for the monoplane, the latter figure being apparently characteristic of the Fokker (see R. & M. 1096), and that the profile drag coefficient is unchanged.

The third (C, Fig. 3) represents an intermediate (and possibly more rational) assumption, that the profile drag coefficient is proportional to the maximum lift coefficient. This leaves type C aerodynamically identical with A except that its chord is reduced in the ratio of 0.55 to 0.70 and certain alterations are possible in the tail length and areas.

Figs. 9 and 10 show corresponding views of the Junkers G.31 and the B.F.W. M.20 for comparison of general proportions.

The above comparison is based on the assumption that the parasite drag of the wing bracing of the biplane is entirely eliminated in the monoplane, but

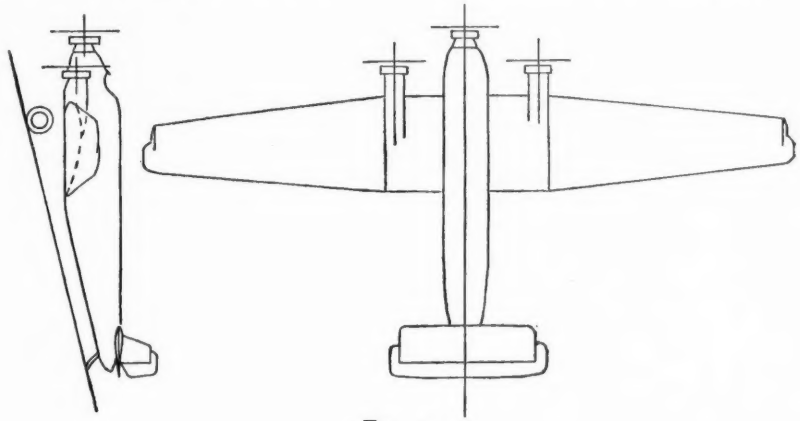

FIG. 9.

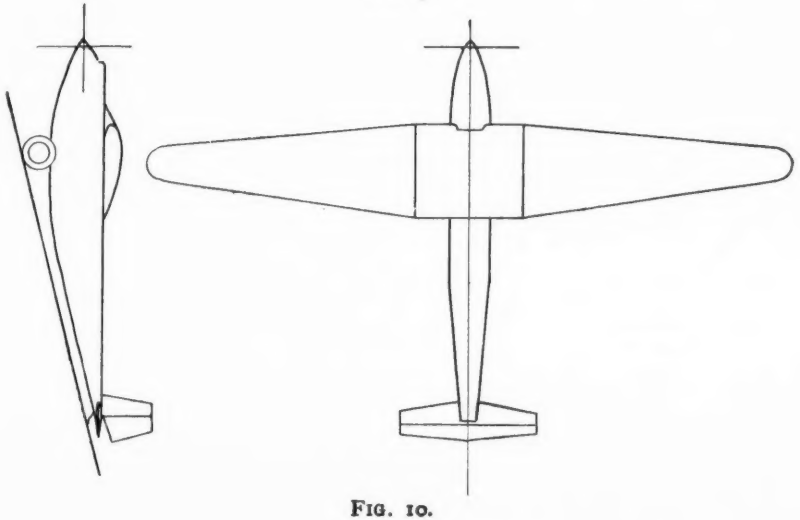

FIG. 10.

that in other respects their parasite resistances are the same. These are both favourable to the monoplane.

What we have done up to the present is fairly commonplace. In fact, I feel that every designer has probably been through something equivalent to it—designers are not so unintelligent as some of those who criticise their efforts would have us believe. In case anyone feels any qualms on the score of " aspect ratio " (for even to-day there appears to be some reluctance to recognise how greatly we are indebted to Prof. Prandtl—and I think I ought to add Mr. Glauert—for clarifying our ideas on the economics of wing design) I may note that the adjustment of the various proportions described in Appendix I., and used above, is precisely equivalent, in the language of ten years ago, to selecting the proper aspect ratio. I have no doubt that the aeroplanes shown in Figs. 1, 2 and 3 are comparable on the basis I have chosen—a fixed total weight, stalling speed, maximum b.h.p., take off (measured by angle of climb), stability and control—and that the monoplanes will cruise at speeds to four to five per cent. higher than the biplane on the same fraction (approximately two-thirds) of the maximum b.h.p. They will also require correspondingly less fuel for the same range in still air. But what of strength and structure weight? How are we going to make the monoplanes shown with no external bracing, and how much will they weigh?

We have here to take into account considerations which cannot be expressed with the same precision as we are able to attain with performance and other characteristics of the same nature.

Let us first agree on a standard of strength. Our own standards of airworthiness have served us well. They are a peculiar mixture of bald empiricism, simple deductions from first principles, and sheer concessions to our own impotence in the face of what I think may undoubtedly be called natural laws. They furnish us with at least one excellent instance of the results of carrying matters to what is generally—and I think incorrectly—termed a logical conclusion. They arose like the Phœnix from the ashes of the late war, but unlike that bird, their wings were somewhat scorched at their birth. With nursing, and the tender care of our admirable Airworthiness Department, they have almost lost their scars, but they are still weak in places—inclined to swing a little when taking off and, it would seem, to dive vertically at their terminal velocity on the slightest provocation.

I doubt if any other set of analogous regulations is in any better state. Building rules, Board of Trade regulations, Lloyd's classification and so on, are very similar. We must face the fact that in civil work safety is a paramount consideration, demanding wider margins for our ignorance, whether realised or only suspected, than are permissible in war. Based as our airworthiness regulations were on war experience, it is remarkable that our civil aeroplanes have proved so free from essential weakness, and have at the same time shown themselves to be commercially as good as, or even better than, those built to less severe rules.

Taken generally, I think our regulations are reasonable, and I should be sorry to see them weakened. In one respect I think they are illogical—the requirement concerning the vertical dive at terminal velocity. It appears to me that this should find no place in regulations for civil aircraft of the size and type we are discussing. Whatever the general opinion on this may be, it is an undoubted fact that it is a requirement which reacts unfavourably on the monoplane, as I shall show. Moreover, the monoplanes we think of have been developed under regulations which have either no corresponding requirement (as, I believe, in Holland), or a much less stringent one (as in Germany).

I propose to adopt our own regulations as a basis, but to discuss the influence of the terminal velocity dive separately.

Passing to the problem of the actual construction, we meet with the difficulty that we have very little experience of our own upon which we can base an estimate of structure weight. I have endeavoured to meet this in the following way. I have collected information from designers and constructors in this and in other countries concerning the structure weight—in particular the weight of the wings—of monoplanes and biplanes. I should like here to thank all those who have helped me in this way. I do not regard their action in this as entirely a personal matter, but rather as an expression of what I hold strongly to be the only sound view on the question of sharing of information in an industry such as ours. It was first pointed out, I believe, by Mr. North that if ten equally capable producers of similar articles share information of any type, each stands to gain nine times as much as he gives. I hope that those who speak after the lecture will give their views on this matter. I should personally be glad to see some advance by the S.B.A.C. on their present attitude.

When it comes to applying a similar principle to other countries, it is easy to see difficulties. It is, I think, remarkable that the principal foreign designers to whom I applied gave me what I wanted without reservation—an example of the advantages of conversations between individuals as a means of settling international problems. One presumes, of course, that they know one another. I cannot pretend that all the various firms abroad to whom I applied know me personally. But they know this Society and what it stands for. I am glad to think a statement of the purpose for which I wanted the information was sufficient, and I think the Society will join with my expression of thanks to them.

I will deal first with biplanes of English construction. The information concerning these will be found tabulated below (Table II.). In the first place it is necessary to agree on a basis on which a single figure of the weight of the wing structure can be interpreted. My own conclusion is set out in Appendix III. and may be summarised as follows. Each half of the wing structure of an aeroplane whose main loads are concentrated in the fuselage is a cantilever, loaded approximately uniformly. The ratio of the weight of such a structure to the load it supports may be expected on general grounds to be proportional to the span of the cantilever, if certain restrictions as to geometrical similarity of outline and a modified geometrical similarity of details are observed. Some such statement as this has become almost common form in papers on any topic concerned with aeroplane structures—the trouble is to make any sense of its consequences. One can readily deduce from it (and some selected numerical data) either that an aeroplane of 200ft. span is a contradiction in terms, or that aeroplane designers are remarkably skilful in cheating the principles of mechanics. To steer a middle course is difficult if one wishes to get anywhere. I have found that the data representing English biplanes fits with certain exceptions fairly well in the following formula:—

$$s_w = \frac{0.25/w + \{ 0.04\,(B/100) + 0.01\,(C/10) \}\, F}{1 + \{ 0.04\,(B/100) + 0.01\,(C/10) \}\, F}$$

where s_w = (weight of wings) ÷ (weight of aeroplane).
w = wing loading.
F = load factor.
B = span.
C = chord (mean).

The comparative figures are shown in Table II., and Fig. 4 shows certain typical ranges, each associated with an appropriate load factor. Such a formula cannot be expected to give reliable indications if we venture far outside the range covered by our data. What then is its use? If we are allowed to use our formula only within the range covered by our facts, why not use the facts

themselves, and have done with it? In effect we do so, but even within their own range they contain considerable variation of certain factors (*e.g.*, the wing loading, span, chord, and load factor in various combinations) and it will be useful if we can do no more than identify separate effects of these. I shall use this formula merely as a means of averaging intelligently—as I hope you will agree it does—among the aeroplanes of which I have collected particulars.

There are many reasons why such a formula cannot be expected to give more than a general agreement with actual weights. Apart from mere formal inadequacy, there are such points as the absence of exact geometrical similarity among the several machines (though I think that is not a vital point), the spreading of the load over the wings on the larger machines, the different techniques involved, and the time factor—the designs mentioned extend over just half the history of mechanical flight. But more important is the uncertainty

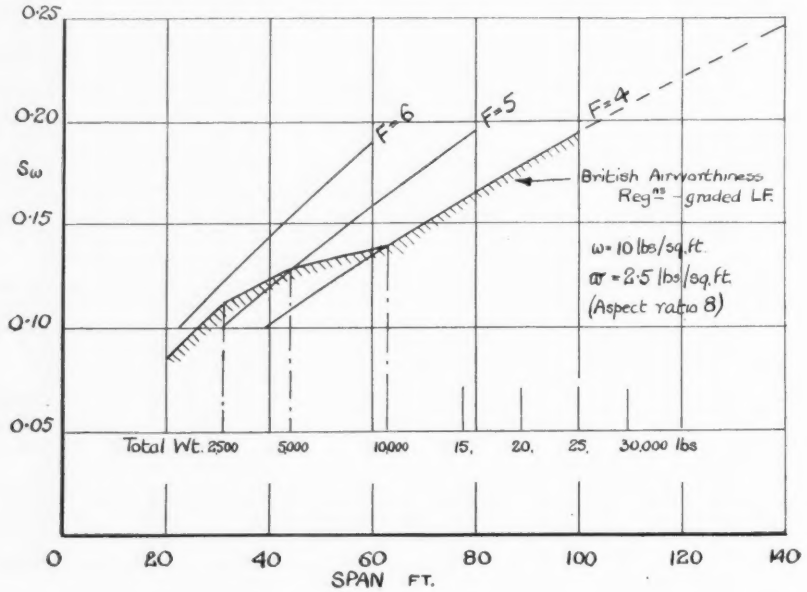

FIG. 4.

as to the load factor. Not only are the numbers used *calculated* load factors, but they are in fact far from uniformly observed. Moreover, an appreciable part of the structure is influenced by the terminal velocity dive, which is not similar in its effect to the general load factors (which, it may be noted, being practically proportional to one another are both allowed for by the factor F).

For these reasons I do not propose to discuss the discrepancies between my formula and the actual figure, with one exception, the V.1500.

When Mr. Handley Page sent me the figures, I added to my thanks the remarks that he had upset all my nice calculations. He replied (I hope he will enlarge on the point in the discussion) that he attributed the light weight to very careful and rather elaborate combination of materials. I venture the opinion that designing strictly to the specified factors had something to do with it. I am convinced that our structures suffer appreciably by accumulation of margins of strength that are seldom of any advantage.

TABLE II.

BIPLANES OF BRITISH DESIGN.

Firm.	Type.	Total weight W lbs.	Wing area S sq. ft.	Span B ft.	Mean chord C ft.	Wing loading $w = W/S$	Span loading $m = W/B^2$	Load factor F	Wing weight $\div W = str$	str from formula (App. III.)
Armstrong Whitworth	Ajax	3800	382	39	6.2	9.9	2.50	5.2	0.120	0.126
	Atlas	4100	382	39	6.2	10.7	2.70	6	0.145† / 0.139‡	0.138
	Argosy	18000	1900	89.5	11.1	9.55	2.24	4	0.180	0.180
	Awana	18400	2300	105	11.9	8.0	1.67	4	0.214	0.204
De Havilland	Canberra	7000	630	52	6.3	11.0	2.60	4.8	0.112	0.136
	Hercules	15700	1547	79.5	10.3	10.2	2.50	4	0.156	0.165
Handley Page	W.10	13800	1481	75	10.2	9.3	2.45	4	0.164	0.162
	Hinaidi	14500	1471	75	10.2	9.9	2.57	4.5	0.150	0.173
	V.1500	30000	2911	126	12.5	10.3	1.89	4	0.172	0.218
Vickers	Vivid*	5550	590	45	7.0	9.4	2.74	6	0.142	0.153
	Virginia*	17600	2194	87	13.0	8.0	2.32	4	0.172	0.188

* Duralumin structure. † Wooden structure. ‡ Steel structure.

I might perhaps mention that Mr. Walker considers the D.H.61 " Canberra," which is remarkably light, to represent a modern biplane, in preference to the " Hercules " which—so rapidly do we move—is now merely history; and that the all-metal machines (excepting covering) included in the table are all appreciably below my standard. It is in fact clear that we may reasonably expect to do slightly better than the formula suggests.

Turning to monoplanes, I give in Table III. the particulars I have collected.

The partially externally braced monoplane, so popular in the U.S.A. for small and medium-sized machines, must in the nature of the case be intermediate in characteristics between the internally braced monoplane and the biplane. We may expect to arrive at a clearer conclusion if we confine our attention to a comparison between the latter. Moreover, we have no information on the former type for large sizes except that contained in Dr. Dornier's paper. I have included this in Table III., which serves to bring out one point of interest—there is little difference, between the biplane and the externally braced monoplane, in the proportion of the total wing weight which is due to the external bracing. In regard to the low wing weights quoted by Dr. Dornier, these are all associated with so high a wing loading that it is difficult to make a fair comparison.

Of the internally braced monoplanes probably the most interesting are the Junkers and the Fokker. They present a remarkable contrast in material and in general technique, and the privilege of a visit to their works (which I have had) is one to be desired by every aeroplane designer. I doubt whether any lighter or more efficient schemes, using the material each prefers, could be devised.

The Junkers G.31 and G.24 set us one peculiar problem. Their respective total weights are 17,800 lbs. and 14,300 lbs., and their wings are identical, weighing 2,800 lbs. or 15.6 and 19.5 per cent. of their respective total weight. In such a design it is, I think, logical to add the weight of the " wing structure " passing through the body, which I estimate to bring the percentages up to 18 per cent. and 22 per cent. approximately. I can only presume that the G.24 was built to higher load factors than are now required, and that the strength of the wings was sufficient for an increased total weight. I believe I am correct in saying that for the G.31 a load factor of just under 4 is required, equivalent on the above assumptions to just under 5 for the G.24. The J.13, an older though essentially similar type, was tested at R.A.E. both structurally and aerodynamically. The wings weighed 12.7 per cent., which I propose to increase to 15 per cent. for the reason mentioned above. Their load factor at failure was 6.9, which probably indicates a design factor of 6.

The Fokker F.VII. (three engines) has a wing in one complete unit, so that the wing weight (16.7 per cent.) is comparable with the Junkers figures as modified.

The Focke-Wulf " Moewe," a machine of which the Luft Hansa have a high opinion, is very similar in construction and weight to the Fokker. The weights and factors for the Moewe and the Habicht were given me by the makers, the former being marked " approximate."

The B.F.W. machines are as yet little known. They are distinguished by a relatively large span and the weights given are remarkably low.

For the Rohrbach machines and the Beardmore " Inflexible " I was unable to obtain weights. For the " Inverness " the data were obtained from the R.A.E. test, for which I have to thank the Air Ministry. The weight includes an estimate for the central part inside the fuselage.

It will probably be sufficient if we confine our attention to the Junkers and Fokker, representing two widely used types. To appreciate the significance of the figures given some discussion of the strength specification to which they are built must be attempted.

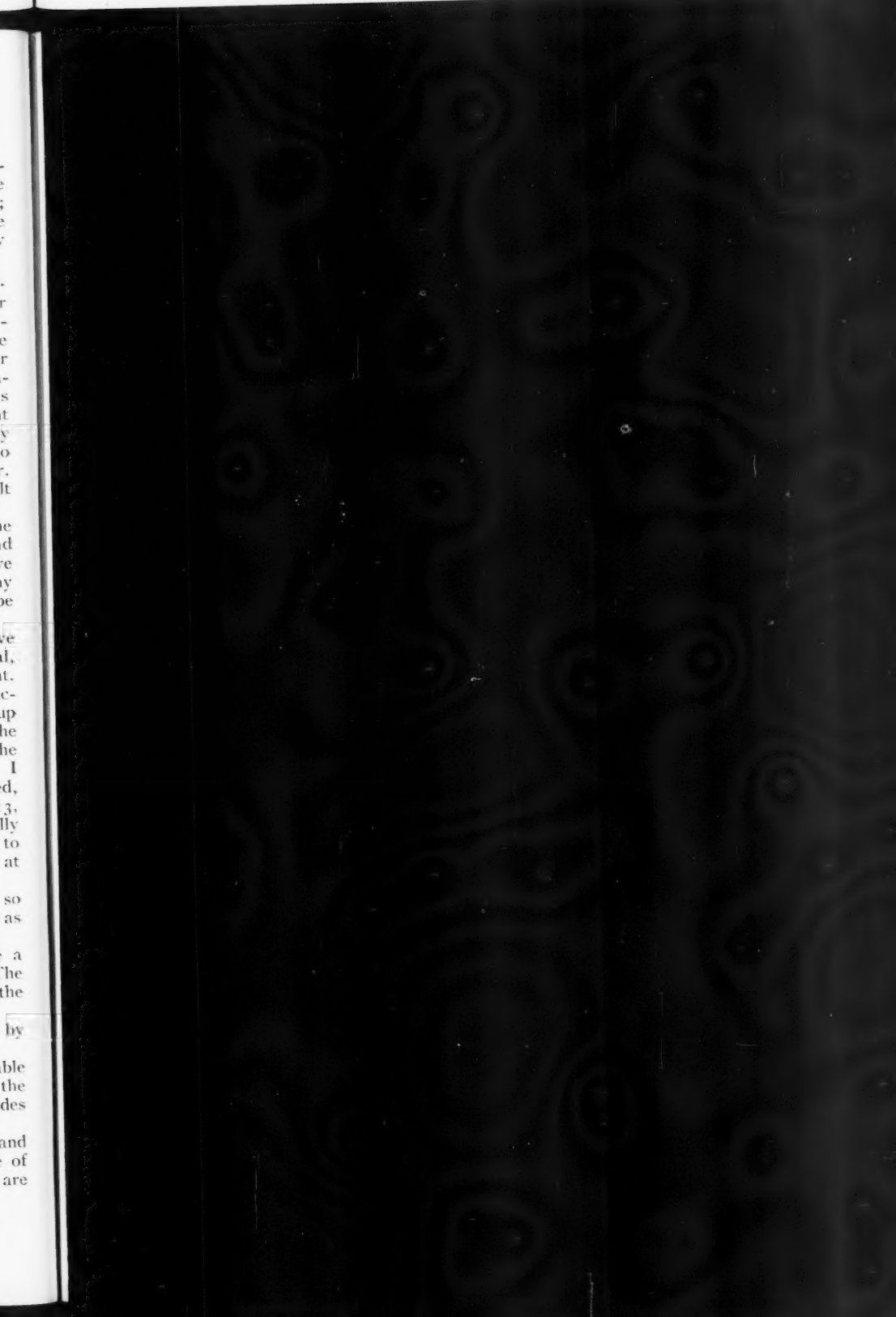

TABLE III.

(i) MONOPLANES (WITH NO EXTERNAL BRACING).

Firm.	Type.	Total weight lbs.	Wing area sq. ft.	Span B ft.	Mean chord ft.	Wing loading $= W/S$	Span loading $= W/B^2$	Load factor	Wing weight $= sw$	Source of data.	Remarks.

Firm.	Type.	Total weight W lbs.	Wing area S sq. ft.	Span B ft.	Mean chord C ft.	Wing loading $w = W/S$	Span loading $\varpi = W/B^2$	Load factor F	Wing weight $\div W = sw$	Source of data.	Remarks.
Junkers	J.13	3900	372	48	8.2	10.5	1.7	6.9	0.15	Air Ministry	Include estimate for wing structure in body
	G.24	14300	1050	98	10	13.6	1.49	5 ?	0.22	Makers	
	G.31	17800	1010	99	10	17·7	1.75	4	0.18	,,	
Rohrbach	Roland	16300	940	85	11	17·3	2.25				Weights unobtainable
	Rocco	23000	1010	85	11.9	22.9	3.18				
	Romar	41800	1820	121	16	23	2.86				
Beardmore	Inverness	13300	756	90	8.65	17.6	1.64	4	0.205	Air Ministry	Includes estimate for wing structure in body
	Inflexible	31400	1936	147	12.25	16.2	1.45	4	0.3	Sq. Ldr. Haig	See Discussion.
B.F.W.	M.18	2650	265	51	5.2	10	1.02	6.5	0.142	Makers	
	M.20	9900	695	83.5	8.3	14.2	1.42	4.7	0.117	,,	
Focke-Wulf	Habicht	3150	345	52.5	6.6	9.1	1.6	6	0.175	,,	Weights stated as "approximate"
	Moewe	8400	670	65.5	10.2	12.4	1.96	5	0.157	,,	
Fokker	F.VII-3M	9900	625	63	10.1	15.8	2.5	4	0.161	Messrs. A. V. Roe and Co. Ltd.	
Ford	5-AT	12500	835	78	11.1	15	2.05	4.5	0.151	Makers	
	4-AT	10000	785	74	10.6	12.8	1.83	4.7	0.167	,,	

(ii) MONOPLANES (WITH EXTERNAL BRACING).

Firm.	Type.	Total weight W lbs.	Wing area S sq. ft.	Span B ft.	Mean chord C ft.	Wing loading $w = W/S$	Span loading $\varpi = W/B^2$	Load factor F	Wing weight $\div W = sw$	Wt. of ext. bracing ÷ wt. of wings.	Source of data.	Remarks.
Dornier	A	1480	166	32	5.2	8.9	1.45	5.4	0.160	0.17		From Dr. Dornier's paper, Journal R.Ae.S., Dec., 1928. Weights include struts.
	B	6300	565	57·5	5.9	11.0	1.91	4.9	0.189	0.14		
	C	13300	1020	74	13.8	13.0	2.42	4.5	0.128	0.15		
	D	31100	1540	94	16.4	20.0	3.57	4.2	0.136	0.13		
	E	113600	5000	140?	35?	22.7	5.7?	4.0	0.145	0.11		
Vickers	Wibault	3183	240	36	6.9	13.3	2.45	7.4	0.168	0.14	Makers	Weights include struts.
Westland	Wizard I.	3260	238	39	6.1	13·7	2.15	7·4	0.120	0.18	,,	
Hamilton	H.45	5650	380	54.4	7	14.8	1.9	7.2	0.134	—	,,	Wing only (approximate).
Fairchild	F.C.2	3600	290	44	7	12.4	1.86	7·5	0.150	—	,,	Weights include struts.
	F.C.W.2	5500	332	50	7	16.6	2.20	7·5	0.119	—	,,	
Mahoney Ryan Brougham		3300	295	42	7	11.2	1.87	?	0.090	—	,,	Wing only.
Travel Air 6000		4100	282	48.5	6.5	14.5	1.75	6.4	0.130	—	,,	Weight includes struts.

The German airworthiness regulations are in my opinion framed in a remarkably logical manner. Their basis is a factor of safety of 1.8 on load factors (for the "normal" class) of $n=2+2/(W+2)$, where W is the weight in metric tons, *i.e.*, for the G.31 a total of $1.8\times 2.2=3.96$. For the high speed condition the factor is approximately two-thirds of this. The terminal velocity dive is represented by the same attitude of flight (approximately zero lift) at a speed not greater than $2\sqrt{n}\times$ the stalling speed, *i.e.*, $3\times$ the stalling speed, with the same factor of safety (1.8). Stalling speed is taken to correspond to ordinary wind tunnel data, giving probably about 0.7 for the maximum lift for the Junkers and hence a stalling speed for the G.31 of about 70 m.p.h. Taking the moment coefficient of the wings at zero lift to be -0.05, the corresponding tail load (including factor) is about one-third W. To comply with our airworthiness regulations more than twice this load would be required. I will take it that approximately the same conditions apply to the Fokker.

This considerable difference in tail load is reflected in a corresponding torque on the wing structure. Taking the weight of the aeroplane $\times$ the chord of the wing as a unit, my estimate of the torque (including factor) on the G.31 is 1.05. On our requirements it would be 2.25. It is difficult to assess its effect, but I think it would probably involve an increase of weight of about 10 per cent. In the Junkers this would take the form partly of a thickening of the covering, since this is the part of the structure mainly concerned with resisting torsional stresses. Probably some increase in the diagonal bracings would also be required, since these are responsible for distributing the air forces (which consist of fairly well localised upward and downward pressures over the rear and forward parts of the chord respectively).

The comparatively poor torsional strength and rigidity of any essentially laminar structure is a crucial difficulty in monoplane design, and the greater the torque in comparison with the maximum transverse loads, the more serious becomes the problem of coping with it. Even with aerofoils of a comparatively high thickness-chord ratio (0.15 and upwards) it is doubtful whether adequate torsional stiffness can be obtained except by use of a stiff covering for either the whole (Junkers and Fokker) or a part (Dornier and B.F.W.) of the wing. But for wing loadings of the order of 10 lbs./sq. ft. the large chord, in conjunction with a comparatively heavy covering,[2] would make the structure uneconomical, and we come to a high wing loading and a high maximum lift. The latter involves a large moment coefficient at zero lift, and hence a large travel of the centre of pressure in normal flight and a large torque on the wing in the terminal velocity dive.

The Junkers construction is a brilliant achievement, but it is economical only in conjunction with higher loadings, even in relation to the maximum lift that the model shows (which as I have mentioned does not appear to be attained on full scale), than we consider desirable from the point of view of safety, and a standard of torsional strength less than half that required by British airworthiness regulations.

The normal biplane is precisely the form of structure which has a natural torsional rigidity. In Appendix IV. I have set out certain investigations on this point which I suggest are worth the consideration of designers. By the conventional method of calculating the strength of a biplane structure, in which certain bracing (incidence wires) is considered to be inoperative, we deliberately shut our eyes to this essential feature—torsional stiffness. I estimate that such a structure is some $2\frac{1}{2}$ times as stiff in torsion as is implied in our methods and generally appreciably stronger (though not in the same ratio). This high torsional stiffness has an influence which may be important and will in all prac-

[2] On the Junkers J.13 the covering, including longitudinal stiffening strips, weighs between 0.7 and 0.4 lbs. per sq. ft. of double surface.

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tical cases be helpful on the distribution of loads in the members of the structure, whatever the nature of the load may be.

For the monoplane such considerations are vital, and in so far as we recognise them in monoplane and not in biplane design we are unreasonably handicapping the biplane.

Even with this handicap the biplane appears to be lighter than the equivalent monoplane. In estimating the weight of the latter from the information we have accumulated we have to take into account the following factors:—

(1) For the wings, the large chord, involving thicker covering or more internal bracing, or both;
(2) For the rest, the extra length of body (involving also extra depth), and the change in tail surfaces; and
(3) For both, the increase in strength required to cope with the terminal velocity dive.

In Table IV. I give my estimates for the three monoplanes of Figs. 1, 2 and 3. We start from the known weight distribution of the biplane. It will be seen by comparison with other biplanes by means of the formula referred to earlier that the weight of its wing structure is representative. As regards the rest of the structure, I think it may also be taken as typical. For the monoplanes, the weight of the engine, etc., remains unchanged, and that of the fuel and tanks is reduced in inverse proportion to their cruising speeds. The wing structure weight I have estimated from the actual weight of the G.31 and F.VII. given above, allowing for the factors just mentioned. The weight of the rest of the structure is derived in a similar way using the weights of the appropriate details on the biplane as a guide. For comparison the actual weights of the G.24, G.31 and Fokker F.VII. are given in parallel columns. Direct comparison of the paying loads is meaningless as their power plant and fuel weights are entirely different, but they serve as a guide to the structure weights.

If these figures are accepted, it appears that the first monoplane (A) is handicapped by its large wing surface, corresponding to the assumption of the same maximum lift coefficient as the biplane (0.55). It is important to notice, however, that our full scale evidence on the J.13 suggests that this applies to the Junkers wing. The paying load is reduced to 65 per cent. of that of the biplane, and the cruising speed rises 4 per cent.

Monoplanes B and C are in a much better case, carrying 79 and 78 per cent. of the paying load of the biplane, with cruising speeds 5 per cent. and 4 per cent. higher. I think C is more representative than B, the assumption of a profile drag coefficient for the latter equal to that of the biplane being unduly optimistic.

These figures all refer to aeroplanes with a comparatively moderate range. If we double the fuel carried, the paying load of the biplane is reduced by 45 per cent. and the *relative* paying loads become: biplane 100, monoplanes A 40, B 67, C 64.

In all cases allowance has been made in the fuel for the increase of cruising speeds of the monoplanes at the same engine power, and for a reduction in cabin furnishing, etc., in proportion to the number of passengers. The latter allowance is somewhat too generous, an appreciable part being independent of the number of passengers.

In summary, we must expect to lose some 20 per cent. of the paying load of a machine of the type I have taken to represent present-day commercial biplanes, if we transform it into a monoplane. This loss will increase as the range increases. We may expect a rise of 4 per cent. in the cruising speed, and an equal reduction in fuel consumption (for a given range). The loss is due to the need for preserving our standards of safety. I propose to leave to those who have the necessary experience the task of deciding whether in the other

TABLE IV.

COMPARISON OF BIPLANE AND MONOPLANES.

(ii) PERCENTAGE WEIGHTS.

Type.	Biplane.	Monoplane A.	Monoplane B.	Monoplane C.	Junkers G.24.	Junkers G.31.	Fokker F.VII.
Power plant	15.7	15.7	15.7	15.7	21.2	18.8	18.8
Fuel + tanks	13.7	13.2	13.0	13.2	21.5	21.5	15.0
Wings	18.0	24	22	21.5	22.0	17.7	16.2
Rest of structure	18.1	23	21	21.5	13.9	21.8	21.9
Disposable	34.5	24.1	28.3	28.1	20.1	21.1	28.1
Crew + equipment ...	4.4	4.4	4.4	4.4			
Passengers + luggage ...	25.3	16.6	20.1	19.9			
Equipment	4.8	3.1	3.8	3.8			
Lbs./b.h.p.	16	16	16	16	16	13.2	15.9
b.h.p./passenger	55	83	69	69	—	—	—
With fuel for double range.							
Disposable	20.8	10.9	15.3	14.9			
Passengers + luggage ...	13.8	5.5	9.2	8.8			
Diagrams	—	Fig. 1.	Fig. 2.	Fig. 3.			

TABLE V.

A COMMERCIAL AEROPLANE TO CRUISE AT 150 M.P.H.

Type.	Biplane.	Monoplane.	Remarks.
Weight	28000	28000	
Wing area S	2300	2000	Assuming biplane K_L 0.6, monoplane K_L 0.7.
Profile R_o/W	0.025	0.025	
Parasite R_p/W	0.030	0.022	Difference due to wing bracing.
Induced R_i/W	0.030	0.034	
Lbs. per b.h.p. cruising	13.9	15.8	Assuming $\eta=0.85$, $f=0.9$ (see Appendix I.).
Lbs. per b.h.p. maximum	10.4	11.9	Cruising at three-quarters max. b.h.p.
Span B	96	102	
Chord C	12	19.5	
Percentage weights.			
Power plant	24	21	In ratio of max. powers.
Fuel and tanks	16	14	,, ,,
Wings	18	22	} Estimated as explained in text.
Rest of structure	18	21	
Disposable	24	18	
Crew + equipment	4	4	
Passengers + luggage	16	14.4	
Equipment	4	3.6	
Horse-power per passenger ...	123	120	

respects which I mentioned at the beginning of this lecture the monoplane or the biplane is to be preferred.

In what way may we anticipate that the position is likely to change in the near future? The developments I can foresee at the moment appear to me to contain equal possibilities for both monoplane and biplane, with one exception. If for some reason—it must be a good one—the permissible stalling speed were materially raised, say, to 65 or 70 m.p.h., the monoplane would gain more than the biplane, for their relative spans would remain much as I have indicated, and a reduction in chord beyond a certain point is uneconomical for the biplane unless satisfactory wing sections of still greater thickness-chord ratio can be devised. But I confess I do not think such a rise in stalling speed is justifiable. Adequate control above the stall may permit of a slight rise, but so far this has not been achieved with wing sections of the types that are essential to monoplane design. The case of the admittedly good control of the Fokker machines at low speeds may be advanced, but such evidence as I have seen on this suggests that it refers really to speeds above the stall, which is virtually equivalent to reducing the effective maximum lift coefficient. There does in fact seem to be something in the nature of a real bar to effective maximum lift coefficients greater than about 0.6—and we can reach that on a biplane.

I said at the beginning of this lecture that I proposed to consider only *commercial* aeroplanes, and I interpreted that as limiting the cruising speed to something less than 100 m.p.h. For this speed we provide at present about 60 b.h.p. (on the full rating of the engine) per passenger and use about 40. What can we do to raise the cruising speed, apart from providing more power (which is precisely what will make civil aviation uncommercial)? Only by reducing the parasite resistance to about one-half its present amount can we contemplate a commercial aeroplane cruising at 150 m.p.h. In Table V. I give a suggestion for the chief proportions of such an aeroplane of moderate range as a monoplane and as a biplane. The take-off disappears as a criterion, being for both much in excess of present standards, and the monoplane can reap the full benefit of its lower resistance, requiring some 13 per cent. less power and less fuel. I have assumed that we can succeed in reducing the bracing resistance of the biplane to 30 per cent. of the profile drag of the wing, as suggested earlier—an easy task in comparison with that of reducing the other parasite resistance. I estimate the gross paying load of the monoplane to be about nine-tenths of that of the biplane. About 120 b.h.p. per passenger will be required, about 90 being used at cruising speed. I think the monoplane has now a slight advantage. We have a long way to go before we can reach this stage. We must become more prosperous—for we shall have to pay for our 120 h.p. We must learn also how to reduce the resistance. Probably by then we shall have learnt how to make still better biplanes.

I desire to acknowledge my indebtedness to the following firms, in this and other countries, who were good enough to supply me with information concerning the weight, strength, and the characteristics of their aeroplanes:—

Messrs. Armstrong, Whitworth Aircraft, Ltd., Coventry.
Messrs. Wm. Beardmore and Co., Ltd., Dalmuir.
The Bristol Aeroplane Co., Ltd., Bristol.
The De Havilland Aircraft Co., Ltd., Edgware.
Messrs. Handley Page, Ltd., Cricklewood.
Messrs. A. V. Roe and Co., Ltd., Manchester.
Messrs. Vickers (Aviation), Ltd., Weybridge.
The Westland Aircraft Works, Ltd., Yeovil.
The Fairchild Airplane Mfg. Corpn., Farmingdale, New York.
The Hamilton Metalplane Co., Milwaukee, Wisconsin.
The B.F. Mahoney Aircraft Corpn., San Diego, California.
The Stout Metal Airplane Co., Dearborn, Michigan.

The Travel Air Mfg. Co., Wichita, Kansas.
Bayerische Flugzeugwerke A.G., Augsburg.
Dornier Metallbauten G.m.b.H., Friedrichshafen.
Focke-Wulf Flugzeugbau A.G., Bremen.
Ernst Heinkel Flugzeuwerke G.m.b.H., Warnemünde.
Junkers Flugzeugwerk A.G., Dessau.
Rohrbach Metal Flugzeugbau G.m.b.H., Berlin.

I have also to thank the Air Ministry for particulars of tests carried out at R.A.E. on the Junkers J.13 and the Beardmore-Rohrbach "Inverness"; and the Deutsche Luft-Hansa for information concerning the German strength requirements.

APPENDIX I.

Performance

1. *Symbols* (in any consistent units).

W = total weight.
S = wing area.
B = span.
$w = W/S$, the wing loading.
$w = W/B^2$, the span loading.
V = speed (general).
V_o = cruising speed.
V_c = take-off speed.
V_s = stalling speed.
$R_{p1} = r_1 \rho V^2$ = parasite resistance not in slipstream.
$R_{p2} = r_2 \rho V^2$ = parasite resistance in slipstream.
$R_p = R_{p1} + R_{p2}$.
K_L = maximum lift coefficient.
k_{Do} = profile resistance coefficient of wing

(variation of which over the working range may, if necessary, be taken into account by writing $k_{Do} = \alpha + \beta (k_L - k_{Lo})^2$, where k_{Lo} is the lift coefficient for minimum k_{Do}. In the problem discussed this refinement is not generally necessary).

R_o = profile resistance.
R_i = induced resistance.
σ = biplane factor for induced resistance.
e = number of engines.
Z = brake power of each engine.
η = airscrew efficiency.
D = airscrew diameter.
T = airscrew thrust $= Z\eta/V$.
(R/R_o) = slipstream factor.
θ = angle of climb.

2. I shall assume that $R/R_o = a + b\,(T/\rho V^2 D^2)$ and write $f = br_2/eD^2$.

Since

$$\theta W = eT - \{ R_o + R_i + R_{p1} + (R/R_o) R_{p2} \} \quad . \quad . \quad . \quad (1)$$

it follows that the performance is completely given by the equations

$$W = K_L \rho S V_s^2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(neglecting the slipstream effect on lift) and

$$\theta W + k_{Do} \rho V^2 S + (r_1 + a r_2)\, \rho V^2 + ([1 + \sigma]/\pi)\, (W^2/B^2)\, (1/\rho V^2) - \eta\, (eZ/V)\, (1 - f) = 0 \quad . \quad . \quad . \quad . \quad (1.1)$$

or

$$\theta + R_o/W + (R_{p1} + a R_{p2})/W + R_i/W - \{ \eta\, (1 - f)/V \}\, (eZ/W) = 0 \quad . \quad (1.2)$$

This will also apply to a monoplane if σ is given the appropriate value (and here includes the δ of Glauert's "Aerofoil Theory." For a normal biplane its value is approximately 0.6, for a monoplane of constant chord, etc., 1.05).

I propose to take ρ throughout at its standard ground level value, since we are concerned mainly with conditions at or near the ground. There is no difficulty in extending the work to cover variation of ρ if desired.

If for convenience we regard R_o, etc., as referring to the condition when $V=100$ m.p.h., and express all speeds in 100's of m.p.h. and power in horsepower, these become

$$W=51\,K_L S V_s^2 \quad . \quad . \quad . \quad . \quad . \quad (2.1)$$

$$\theta+\{(R_o+R_{p1}+aR_{p2})/W\}\,V^2+(R_i/W)/V^2-3.75\,\{\eta\,(1-f)/V\}\,(eZ/W)=0 \quad (1.3)$$

4. *Take-off.*—I assume that V_c, V_s, θ, W, η, f and eZ are the same for both monoplane and biplane. It appears that a is generally nearly 1. All slipstream effects are then contained in the factor $(1-f)$ which varies from 0.9 to 0.8. Comparative little of the wing bracing is affected by the slipstream so that f may be taken to be fixed without appreciable error.

Using suffixes B and M to distinguish between the corresponding values and (B − M) to denote their difference, it follows that

$$S_M/S_B=K_{LB}/K_{LM} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and

$$(B_B/B_M)^2=(1+\sigma_B)/(1+\sigma_M)\,\{1+(R_o+R_p)_{B-M}/(R_i)_B\,(V_c^4)\} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The last result replaces the simpler one, expressing the equality of the induced resistances only, namely:—

$$(B_B/B_M)^2=(1+\sigma_B)/(1+\sigma_M)=0.78 \text{ approximately,}$$

or

$$B_B=0.89\,B_M \text{ approximately.}$$

The factor in { } in (4) is generally about 1.2, so that we have approximately

$$B_B=B_M$$

5. *Cruising Speed.*—Here $\theta=0$. I assume W, η, f and eZ to be the same for monoplane and biplane, eZ being now some definite fraction of the maximum power (in practice about two-thirds).

If for shortness we write

$$R_o+R_{p1}+R_{p2}=R$$
$$(V_o)_M-(V_o)_B=\delta V_o$$
$$R_M-R_B=\delta R$$
$$(R_i)_M-(R_i)_B=\delta R_i$$

then since δV_o is small it follows from (1.3) that to a sufficient approximation

$$\delta V_o/V_o=\{-V_o^3\delta R+\delta R_i/V_o\}/\{3V_o^3R-R_i/V_o\} \quad . \quad . \quad (5)$$

or, from (4),

$$\delta V_o/V_o=\tfrac{1}{3}\,(-\delta R/R)\,[1-(V_c/V_o)^4]/[1-\tfrac{1}{3}\,(R_i/R_o)/V_o^4] \quad . \quad (6)$$

Appendix II.

Stability and Control

1. *Symbols.*

s = semi-span.
C = mean chord.
A = aspect ratio.
M = pitching moment about transverse axis.
k_m = wing moment coefficient.
α = angle of incidence.
h = fore and aft centre of gravity coefficient.

S' = tail area.
l = tail length.
E = tail "efficiency."
$dk'_L/d\alpha'$ = slope of lift curve for tail plane.
ϵ = angle of downwash at tail.

2. *Fore and Aft Stability.*—I propose to adopt the criterion that the quantity

$$m = (dM/d\alpha)/\rho SCV^2$$

shall be kept the same for the equivalent monoplane and biplane. There is room for difference of opinion here since this quantity is not, strictly speaking, non-dimensional in the absence of geometrical similarity, being essentially greater for the monoplane than for the biplane of the same total weight. But it appears to me that the suggested criterion is logical—moreover, it appears to be virtually adopted by those who have experience in monoplane design.

I assume that a reasonable margin of stability is required which makes it possible to neglect certain minor effects. We thus have

$$m = dk_L/d\alpha \{ dk_m/dk_L + h \} - (S'l/SC)\, E\, (dk'_L/d\alpha')\, (1 - d\epsilon/d\alpha) \quad . \quad (6)$$

Further

$$dk_L/d\alpha = \pi A/\{ (1+\pi\beta)\, A + 2\,(1+\tau+\sigma) \} \quad . \quad . \quad . \quad (7)$$

(see Glauert's "Aerofoil Theory," Ch. XIII.) where β and σ are zero for a monoplane and have the average values 0.053 and 0.6 for a biplane; and τ is the same for both monoplane and biplane, varying from 0.12 to 0.20 as A varied from 4 to 8.

The rate of change of moment coefficient dk_m/dk_L is approximately 0.25 for a monoplane and 0.22 for a biplane. The value varies somewhat from one aerofoil section to another, and the theoretical work for the biplane is as yet somewhat unsatisfactory. The above difference, which is important, is probably sufficiently well established for use here.

The rate of change of down-wash with angle of incidence $d\epsilon/d\alpha$ depends on the position of the tail in relation to the wing (l/s) on the aspect ratio of the wings (A), on the spacing of the tip vortices (s'/s), which is itself dependent on the aspect ratio, on $dk_L/d\alpha$ and on the number of planes. From Glauert's "Aerofoil Theory" (Ch. XII.) we have

$$d\epsilon/d\alpha = \tfrac{1}{2}\,(s/s')^2 \{ 1 + \sqrt{\ } \{ 1 + (s'/s)^2\,(s/l)^2 \} \}\, (2/\pi A)\, (dk_L/d\alpha)$$

for a monoplane, and twice that value for a biplane (for which, however, A is also practically double, so that the final difference is small).

The nett effect of these various factors is to make it possible to give the equivalent monoplane either approximately the same tail volume ratio $S'l/SC$, with a centre of gravity in the same position as the biplane, or to keep the same C.G. position and to use a tail volume ratio about 6/7 that of the biplane. In view of the great increase in tail length involved in the former course, the second alternative has been adopted in the text, the particular values used being given in Table I., together with the other corresponding quantities mentioned above.

3. *Rudder Control.*—It appears reasonable to take the rudder volume ratio $S''l/Ss$ as a criterion. Again there is considerable scope for choice of the separate quantities, but since the large chord of the monoplane involves a tail length between 20 and 30 per cent. longer than that of the equivalent biplane, this requirement is on the whole rather more easily met in the monoplane.

There is, however, another important consideration which may in certain cases override the one mentioned above—the need for a certain absolute rudder power to cope with failure of a wing engine. In Table I. the rudder and fin areas chosen are sufficient to cope with which ever happens to be the higher requirement.

4. The other factors involved in stability and control do not impose an appreciably greater tax on monoplane or biplane, with the single exception that so far it does not appear that any effective slotted control has been devised for the wing sections which are essential for monoplanes.

APPENDIX III.

Wing Structure Weight

1. *Symbols.*

W = weight of aeroplane.
W_w = weight of wings.
F = load factor.
S = wing area.
B = span (mean).
C = chord (mean).
$s_w = W_w/W$.
$w = W/S$.

2. It has been usual to attempt to analyse wing structure weight on the basis that the independent variable of greatest influence is wing area. It would seem that a more logical variable is the span. By familiar arguments, a cantilever structure of given outline in one plane, carrying a load distributed in a given manner, can be shown to have a weight proportional to the span and the total load carried. Certain assumptions are necessary concerning the way in which the proportion of individual members are varied, since complete geometrical similarity, while simple, is not even approximately representative of practice. This result may be put

$$(\text{weight of structure}) = b \times B \times (\text{load carried}).$$

For aeroplane work the load carried may be written

$$(W - W_w) F$$

Hence

$$W_w = bB\,(W - W_w)\,F \quad . \quad . \quad . \quad . \quad . \quad (8)$$

This may be considered to apply to the majority of the spars, struts and wires of an aeroplane, provided *general* geometrical similarity is preserved and that the dead load is substantially concentrated.

For the structure which carries the air pressure distributed along the chord to the main structure, namely, the ribs, a formula similar to (8) may be expected to hold, C replacing B.

Certain parts of the structure cannot be expected to fit in with such a relation. For instance, the covering is generally the same from aeroplane to aeroplane, weighing 0.18 lb. per sq. ft. of double surface, doped. There are other minor items which contribute an appreciable amount and can probably be similarly expressed.

Hence we get finally

$$W_w = aS + (bB + cC)\,(W - W_w)\,F \quad . \quad . \quad . \quad . \quad (9)$$

or

$$s_w = \{\,(a/w) + (bB + cC)\,F\,\} \,/\, \{\,1 + (bB + cC)\,F\,\} \quad . \quad . \quad (9.1)$$

It may be noted that the non-dimensional nature of the above formula implies that the constants b and a are of the dimensions $[L]^{-1}$. By taking a simple example they will be found to be proportional to the density of the material used, divided by its limiting stress, which has these dimensions.

To find reasonable values for the constant in such a formula by taking ascertained values of the total is unsatisfactory. Some independent estimate must be attempted.

From the data available for several normal biplanes it appears that the weight of the spars, wings and struts is about 65 per cent. and that of the ribs 20 per cent., the mean aspect ratio ($A=B/C$) being 8. This suggests that b is approximately 0.4 c. Actually the formula

$$S_w=[0.25/w+(0.04\{B/100\}+0.01\{C/10\})F]/[1+(0.04\{B/100\}+0.01\{C/10\})F]$$

agrees reasonably well with most of the data for biplanes given, the marked discrepancies being accounted for by known peculiarities (see Table II.).

4. On general grounds it would appear that a monoplane construction such as the Junkers would follow a relation of similar form but with different constants. Uncertainty as to the proper values of F make it fruitless to attempt any estimate of their values from the data available.

APPENDIX IV.

Torsional Strength and Rigidity of Wing Structures

1. The structural form of a monoplane wing, such as the Junkers or Fokker, is not one which lends itself to any but an approximate estimate of torsional strength. A certain insight into the problem can be gained by considering the bearing of the following simple example. Two thin tubes (A, B, Fig. 5) are firmly held, in bending and in torsion, by a fixed support at one end and by something corresponding to a rigid "compression rib" at the other. A load is applied to the latter as shown. In what proportion is it shared by the two

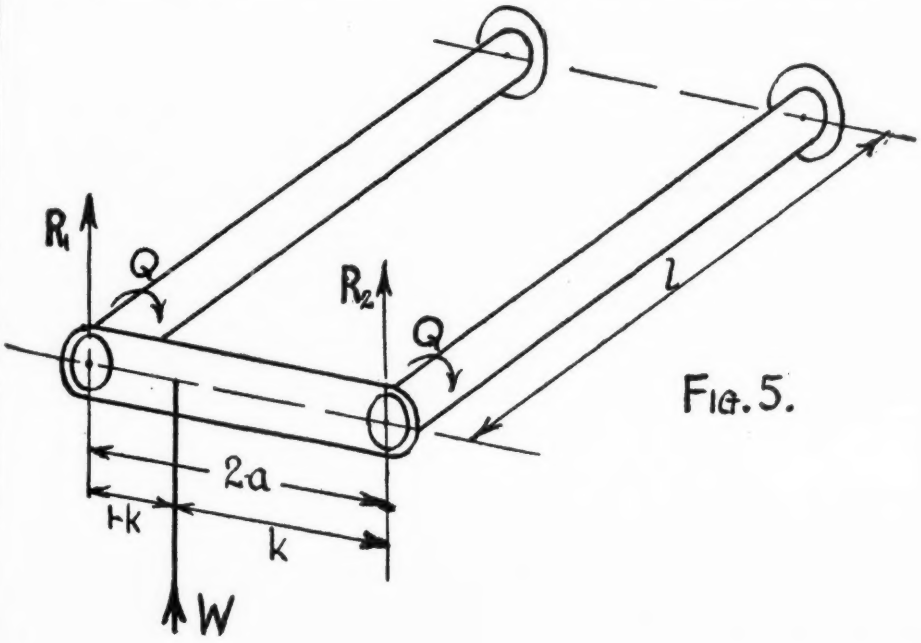


FIG. 5.

tubes, and what is the torque in each? It can readily be shown, using the symbols shown in Fig. 5, that

$$\left.\begin{aligned} R_1/W &= \tfrac{1}{2} + (1-m)\,(k-\tfrac{1}{2}) \\ R_2/W &= \tfrac{1}{2} - (1-m)\,(k-\tfrac{1}{2}) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (10)$$

where

$$m = 1/\{\,1 + (3EI/CJ)\,(a^2/l^2)\,\} \quad . \quad . \quad . \quad . \quad (11)$$

E and C being the moduli of elasticity and rigidity, and I and J the bending and torsional moments of inertia, respectively. For the circular steel tube $EI/CJ = 1.25$ approximately, so that

$$m = 1/\{\,1 + 3.75\,(a^2/l^2)\,\} \quad . \quad . \quad . \quad . \quad (11.1)$$

For comparison with a wing structure a/l may be taken between $\frac{1}{4}$ and $\frac{1}{8}$, so that m is between 0.85 and 0.94. Thus, so long as the load is applied anywhere between the tubes (k between 0 and 1) the transverse load on each tube does not differ from $\frac{1}{2}W$ by more than 15 per cent.

The torque on each tube is given by

$$Q/W \,.\, 2a = \tfrac{1}{2}m\,(k-\tfrac{1}{2}) \quad . \quad . \quad . \quad . \quad (12)$$

In this structure the strength depends but slightly on the position of the centre of pressure. It can readily be shown that the shear stress in the tubes does not exceed 1/10 the direct stress.

It is not suggested that the characteristics of an actual wing are adequately represented in this way, but it may be expected that substitution of an appropriate value for EI/CJ, the ratio of the transverse and torsional rigidities, will give an indication of what may be termed the "effective centre of pressure travel."

In a structure such as the Junkers, the torsional strength is probably not very different from that of a circular tube of the same cross-sectional area as that of the wing and of the same wall thickness, but the transverse rigidity is of course largely due to the tubular "spars." A value of 0.6 for m is suggested.

For a construction such as the Fokker similar remarks apply.

In these structures the "ribs," or their equivalent, in addition to their ordinary functions, have the very important duty of preventing the cross-section of the "tube" from distorting, and thus ensuring the full torsional rigidity and the corresponding sharing of transverse loads all along the spars.

2. In a biplane the problem is simpler owing to the much clearer separation of the functions of the various members. Essentially there is one position of the centre of pressure of a transverse load for which the front and rear girders of an unstaggered equal wing biplane are distorted by equal amounts. The load carried by each is proportional to its rigidity and the stresses in corresponding members are the same. Any departure of the centre of pressure from this position involves torsion of the whole structure. The incidence wires serve practically to keep the cross-section of the "tube" unchanged (they are, in practice, of comparatively high rigidity owing to their short length, especially if designed to act as duplicate bracing).

As a result, so far as the axial loads in the members are concerned, the girder towards which the centre of pressure moves bears less additional load than it would carry if there were no incidence bracing. Moreover, owing to the tension in the incidence wires, the "drag" bracing shares in resisting the effective torsion, as it would in a long structure built up of similar bays under the action of a pure torque applied to a rigid bulkhead at each end, though here the "incidence" or bulkhead bracing along the structure is unstressed. That it is stressed in the ordinary biplane is due to the distribution of the torque along the structure.

3. As a simple example of this effect, consider the structure shown in Fig. 6, loaded only at A and a, where $AB = 2AC = 4Aa$.

Assume (1) that all the spars and struts have the same cross-sectional area,
(2) that all the wires have the same cross-sectional area,
(3) that for an equal length of each, the extensibility of any wire $(1/AE)$ is n times that of any spar or strut.

Using the conventional strain energy method, it can be shown that the tension in the incidence wire Ac is

$$T = [w_1 (10 + 11.2\, n) - w_2 (16 + 11.2\, n)] / [41 + 26.4\, n] \quad . \quad (13)$$

A suitable value for n appears to be 10, which gives approximately

$$T = 0.4\, (w_1 - w_2) \quad . \quad . \quad . \quad . \quad . \quad (13.1)$$

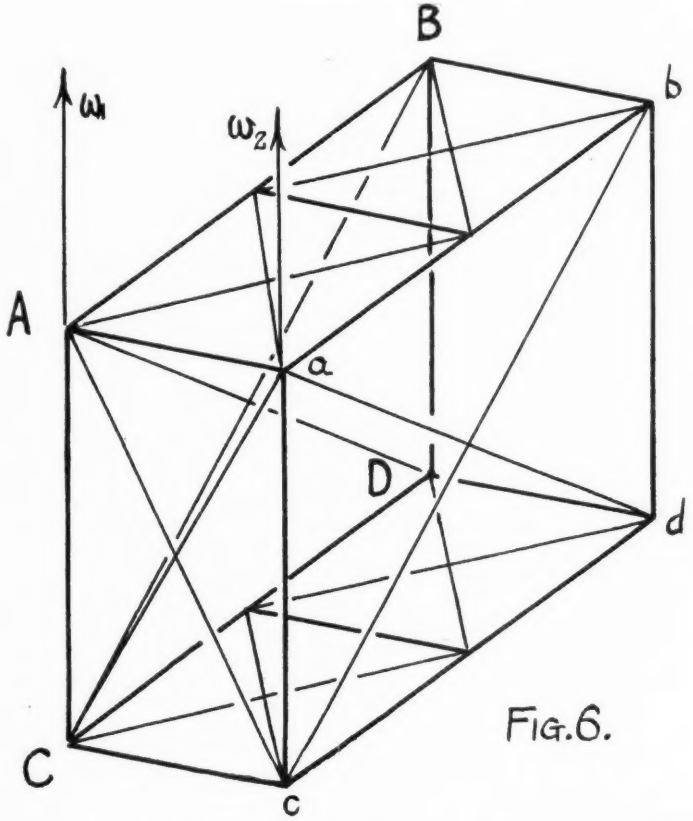


FIG. 6.

Various other typical values for the relative rigidities of the parts, within practical limits, lead to but slightly different values for T.

If w_1 and w_2 are due to a total load $W = w_1 + w_2$ placed so as to divide Aa in the ratio $k : (1 - k)$, it follows that the effective loads on the four girders are as shown in Fig. 7, namely, on the lift girders $\frac{1}{2} \pm 0.28\, (k - \frac{1}{2})$ and on the drag girders $0.36\, (k - \frac{1}{2})$. The similarity between these two expressions and (10) and (12) above will be obvious, suggesting that an equivalent value for m is 0.72.

If $k=0$, corresponding to the centre of pressure being on the front spar, the equivalent lift girder loads are $\frac{1}{2}\pm 0.14$, *i.e.*, 0.64 and 0.36, instead of 1 and 0 which correspond to absence of the incidence wires.

It must be emphasised that these apply only to the *axial* loads in the members and not the transverse loads on the spars, the monoplane having the advantage here.

4. When the loads represented by w_1 and w_2 are in opposite directions, corresponding to the terminal velocity dive, (13.1) becomes approximately

$$T=0.4\,(w_1+w_2) \quad . \quad . \quad . \quad . \quad . \quad (13.2)$$

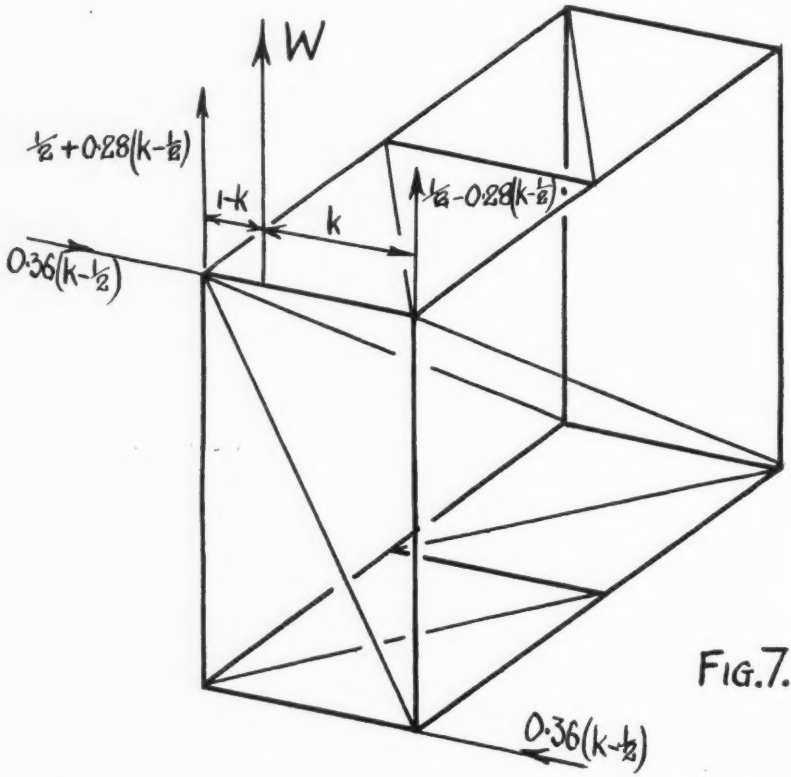


FIG. 7.

This has the effect of changing the effective loads on the lift girders from $-w_1$ and w_2 to $-w_1+0.36\,(w_1+w_2)$ and $w_2-0.36\,(w_1+w_2)$ respectively, and of introducing effective loads on the drag girders equal to $0.18\,(w_1+w_2)$. Since w_1 and w_2 are nearly equal, these changes alter the axial forces in the structure to such an extent that it seems desirable to work out an example from an actual aeroplane. Fig. 8 shows the structure, the loads, and the two solutions, one neglecting incidence wires and the other taking them into account. Further remarks on this matter may be found in R. & M. 769, where the same problem is solved by a different method. An error in the working there is responsible for the difference between the results. This has been corrected above. The essential character of the results is not affected.

It will be seen that the torque appears as a more or less uniform tension in all the wires in any transverse section. The spars are under a corresponding (and negligible) compression. Of the total torque on the structure 40 per cent. appears in the lift girders and 60 per cent. in the drag girders, instead of the whole being borne by the lift girders in accordance with conventional assumption.

It would appear that, if there is no sound objection to taking account of the incidence wires, the terminal velocity dive would be of less moment[3] than is generally believed, even if wing sections were used with characteristics much less favourable than those of R.A.F. 15, to which the above figures correspond.

5. So far as biplane technique is concerned, we may conclude from the above investigation that an appreciable advance could be expected if its design were considered *à priori* from the point of view that it is a structure in which the load distribution is greatly influenced by its torsional stiffness. As an

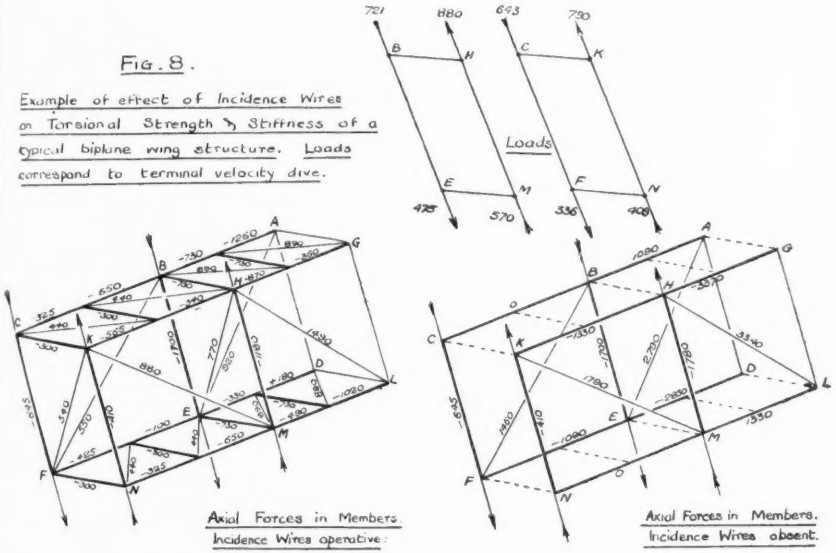


FIG. 8.

Example of effect of Incidence Wires on Torsional Strength & Stiffness of a typical biplane wing structure. Loads correspond to terminal velocity dive.

example, in Table VI. are given the effective loads (as fractions of the total weight) on the front and rear lift girders and the drag girders of the simple biplane of Fig. 6, in the conditions stated, which correspond to the three crucial loads.[4] It must again be emphasised that the transverse loads on the spars are not affected, the redistribution concerning axial loads alone, but it is evident that there is an all round relief.

6. Comparing monoplane and biplane, the need for a construction for the former giving *inherent torsional stiffness* is apparent. Adequate *strength* in torsion could be provided purely by the strength of the two spars in bending, but this would result in extremely heavy spars if the same total torsional *stiffness*

[3] So far as the wings are concerned. Its effect on the tail and fuselage structure remains unchanged.

[4] Two cases are dealt with, one corresponding to a wing section with a large moment coefficient (−0.05) and the other to a section such as R.A.F.15 (−0.015). In both cases the spars are taken to be at 0.15 and 0.65 chord, and the rigidity of the front and rear lift girders is taken to be the same.

TABLE VI.

(See Appendix IV.)

EFFECT OF INCIDENCE WIRES ON AXIAL LOADS IN MEMBERS OF BIPLANE STRUCTURE.

	C.P.F.			C.P.B.			T.V.D.		
(I.) $k_{mo} = -0.05$.	F = 4, C.P. = 0.3.			F = 3.15, C.P. = 0.575.			F.S. = 1.2, Ω = 2.0.		
	Front lift.	Rear lift.	Drag.	Front lift.	Rear lift.	Drag.	Front lift.	Rear lift.	Drag.
Incidence wires neglected	2.80	1.20	—	0.47	2.67	—	−4.1	4.8	—
Incidence wires operative	2.25	1.75	0.28	1.26	1.89	0.39	−0.9	1.58	1.61
(II.) $k_{mo} = -0.015$.	F = 4, C.P. = 0.28.			F = 3.15, C.P. = 0.40.			F.S. = 1.2, Ω = 0.6.		
Incidence wires neglected	2.96	1.04	—	1.57	1.57	—	−1.24	1.44	—
Incidence wires operative	2.28	1.72	0.36	1.57	1.57	—	−0.27	0.47	0.48

NOTE.—The spars are at 0.15 and 0.65 chord. It is assumed that the front and rear lift girders have equal rigidity.

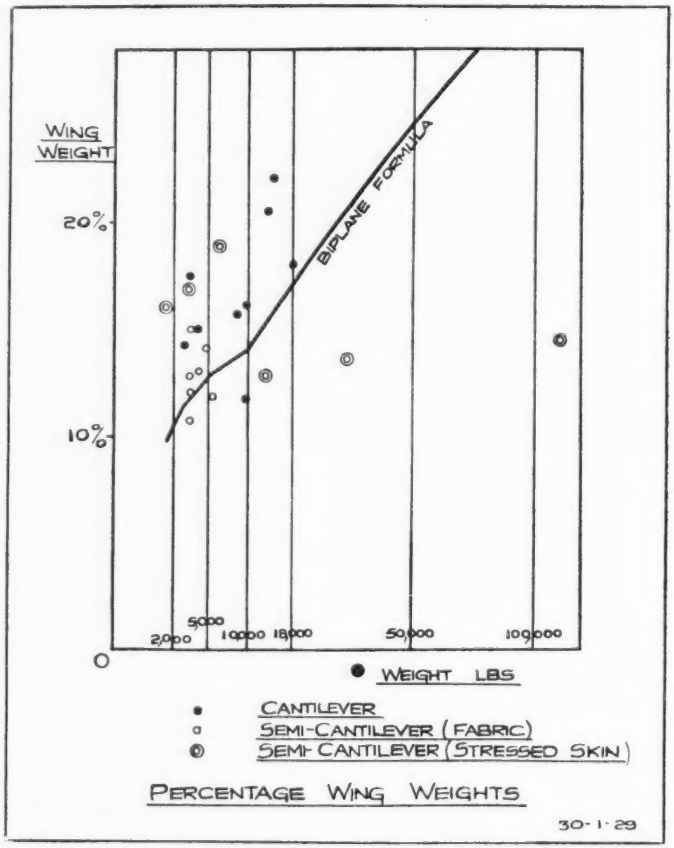
is required as in the equivalent biplane, which does not seem too severe a demand. For not only are the deflections of beams for a given span, load and material (*i.e.*, maximum stress) inversely proportional to their depths, but in the biplane, as has been shown, the twist is reduced to something of the order of 40 per cent. of what it would be if it relied entirely on the bracing of the lift girders and had no inherent torsional stiffness. Thus, in the monoplane either the twist at the wing tip would be some ten times that in the biplane or the maximum stress would have to be greatly reduced by increasing the amount of material present. It is evident that the torsional stiffness of the biplane is almost its most important structural characteristic.

Discussion

The President: The paper was particularly interesting at the moment, inasmuch as a report had just been received from the Society of Automotive Engineers (Aeronautical Section) in America of a lecture having a similar title, delivered in New York by the Assistant Professor of Aeronautics at the Massachusetts Institute of Technology. There was also a report of the discussion, to which Mr. Fokker, among others, had contributed. In the lecture the case for the monoplane and the biplane were set out impartially. Mr. Fokker, in the discussion, had stated that there were in certain cases reasons for building a biplane or even a triplane. The theoretical and practical considerations, concluded the President, must be weighed very carefully, and each case decided upon its merits. From the commercial and civil aspect the President expressed an opinion that the practical advantages offered by the monoplane would gradually secure its wide adoption.

Captain G. T. R. Hill: He recalled that some years ago he had had the pleasure of serving under Mr. Farren at the Royal Aircraft Establishment at Farnborough, and he expressed indebtedness to him for having collected so much information in his paper and its appendices; the latter in themselves contained almost sufficient material for another paper. Captain Hill supported heartily Mr. Farren's plea for a more free exchange of information; everyone agreed that all would gain more than they lost thereby, and he hoped the free exchange of information would become more general in England, as it had, he believed, in America. Having agreed with Mr. Farren on that point, he heartily disagreed with the main conclusions set out in the paper. He added that in expressing his own views he was expressing the views of the Westland Aircraft Works, and, inasmuch as they were earning their daily bread out of biplanes and at the same time were from many points of view attracted towards the monoplane, those views could be accepted as being without very definite bias. Dealing particularly with the weight aspect of the problem, he said he did not question the facts Mr. Farren had collected, or the particulars which, he had stated so modestly, he had reason to suspect were true; nor did he question the logic of Mr. Farren's argument, or the conclusions he had based upon it. It was true that he had designed a bad monoplane, but it was not quite fair to blame the monoplane entirely for being a bad one; he ought himself to accept a little of the blame.

In order to present in a convenient form the information given in the paper with regard to weights, Captain Hill exhibited a diagram on which he had plotted the percentage wing weights from Table III. (ii) in the paper, and had added several more points representing Westland monoplanes, which further supported the data already given.



His first purpose in exhibiting this diagram was to suggest that the weight of the semi-cantilever monoplane with fabric covering was definitely less than that of the full cantilever type. Of the semi-cantilever types, the metal or ply covered machines were the heavier, presumably because they had heavier coverings.

Analysing Mr. Farren's argument, he said Mr. Farren had strengthened the heaviest type of monoplane (the full cantilever type) according to our own airworthiness regulations—which were based on little or no experience of the monoplane type of machine—and had then increased its cruising speed, for what reason he (Captain Hill) did not understand, and had proved, of course, that the monoplane was worse than the biplane. It seemed that it would be fairer to maintain the original cruising speed and to throttle the engine more; in those circumstances a saving in petrol would be effected, and the monoplane would not appear nearly so much worse than the biplane, even admitting the use of Mr. Farren's other assumptions.

With regard to the airworthiness regulations, he said it seemed to him that the nose-diving factor, which was the crucial point, resulted in absurdity when applied to passenger-carrying aircraft. If, for instance, one of the machines of the future, as depicted by Mr. Farren, with tennis courts, etc., on the tops

of the wings, were to get into a nose dive and come down vertically, the whole of the passengers would tumble down together towards the front, and the aeroplane would become so nose-heavy that the pilot could not hope to get the machine out of the dive, and the sooner the wings came off the sooner would the passengers be put out of misery.

In order to make what seemed to him a fairer comparison of monoplane and biplane he outlined the design of a semi-cantilever monoplane more or less on the lines on which the Westland works had had some experience, and the second purpose of his diagram was to show that a percentage weight of between 18 and 19 per cent. was not unreasonable for that proposed monoplane, on the assumption that the monoplane wing weights would increase in the manner indicated by the biplane formula given by the lecturer. With regard to the details, he proposed to use a wing with a nearly stationary centre of pressure, with the result that the nose-diving loading would not have any effect on the wing weight. The fuselage strength in this case was not determined by aerodynamic loads but by tail skid loads, and he would give the aeroplane a normal aspect ratio of about $6\frac{1}{2}$, instead of producing the very short, stubby type of machine such as Mr. Farren had designed. Then he had allowed for the parasitic resistance of the wing bracing of the monoplane to be two-thirds that of the biplane, which was not unreasonable; further, he reduced the engine size slightly, so as to give the same take-off (measured by height attained 500 metres from the starting point). The result he indicated by means of a slide, showing the percentage weights of the monoplane and the biplane (see Table).

	Biplane (Argosy).	Monoplane C.	Semi-cantilever Monoplane.
Total weight, lbs.	18,000	18,000	18,000
K_1	0.55	0.70	0.60
K_{p_0}	0.006	0.0076	0.0065
Profile R_0/W } at 100 m.p.h.	0.0313	0.0313	0.0313
Parasite R_p/W } at 100 m.p.h.	0.0830	0.0651	0.0770
Induced R_i/W } at 100 m.p.h.	0.0224	0.0280	0.0195
Total R/W } at 100 m.p.h.	0.1367	0.1244	0.1278
Wing area S	1,900	1,500	1,740
Aspect ratio	8	$5\frac{1}{2}$	$6\frac{1}{2}$
Span	89.5	91	106
$r=l/c$	3.34	2.75	2.64
Tail length$=l$	37.1	44.6	43.3
Tail area$=S'$	215	160	215
Tail volume$=ar$	0.380	0.297	0.326
Engine horse-power	1,125	1,125	1,080
Rate of climb	1	1	1.04
Cruising speed	100	104	100
Percentage weights:—			
Power plant	15.7	15.7	15.1
Fuel and tanks	13.7	13.2	12.7
Wings	18.0	21.5	18.5
Rest of structure	18.1	21.5	18.7
Disposable	34.5	28.1	35.0
Passengers and luggage	25.3	19.9	25.7
Disposable (with double range) ...	20.8	14.9	22.3
Passengers and luggage (with double range)	13.8	8.8	15.0

Percentage gain of pay load of semi-cantilever monoplane over biplane:—
2 per cent. on normal range.
9 per cent. on double range.

From an examination of the comparison of types, it was clear that the semi-cantilever monoplane was certainly no worse from the point of view of useful load, the engine could be run more throttled, the engine would be slightly smaller also, and the machine would climb slightly more steeply; in other words, a gain was shown on every count. With regard to safety, he said there was no question that the braced monoplane was anything but perfectly satisfactory from the point of view of structural safety. As to aerodynamic safety, he expressed the view that, without slots, the monoplane was the safer; both types of machine, when fitted with slots, had given most excellent results, and there appeared to be no reason in the light of the most recent knowledge for saying that the monoplane was in any way behind in this respect.

In conclusion, he said he did not wish to convey the impression that the Westland works were wedded in the ecclesiastical sense to the monoplane; indeed, should they see anything attractive in any other direction they would seek a divorce from their present attachment. There was no doubt, however, at the moment, that, with its slim and graceful lines, the monoplane was extraordinarily attractive. In his view Mr. Farren was on a sinking ship, though in his lecture he had tried to show how much buoyancy it had; at the same time he had given an opportunity for a few holes to be bored in it, and he (Captain Hill) hoped it would be agreed that some of the holes he had bored were well below the water line.

Major BUCHANAN: He believed it was quite vain to expect to reach agreement, because the matter was as much one of fancy as of fact. There appeared to be national preferences, and, indeed, monoplanes and biplanes were appearing as national characteristics. Mr. Farren seemed to have been trying to guard himself against himself; wherever a point appeared to be favourable to a monoplane he had conceded it, but where a point appeared to be favourable to a biplane he had withdrawn it. The basis of his assumptions, and of his whole paper, was the wing weight of the "Argosy," but the "Argosy" wings were heavier than they would be if they were re-designed in metal. He had compared them with the latest types of monoplane metal structure, and to that extent he had biased his argument against the biplane. With regard to the airworthiness regulations, he said no-one would pretend that they were perfect. As they existed they constituted a growth, quite a sound growth, but they had not always grown quite straight, and there were some faults in them which no doubt should be removed. The nose-diving factor as laid down in these regulations as applied to civil aircraft of normal category was one with which he disagreed. He was glad that Mr. Farren had had a good word to say for British designers.

Mr. C. C. WALKER: To a large extent the considerations which determined whether a machine should be designed as a monoplane or a biplane were practical; those practical considerations might apply within a certain zone of size, but outside that zone of size the proposition might be entirely different. Among the chief virtues of the monoplane were its greater simplicity, the fewness of parts, ease of upkeep, greater ease in entering or leaving cabins, and matters of that sort, until a certain size was reached, but in the case of the bigger machines, even those of the size of the "Argosy," many of those advantages no longer applied. In connection with the bigger machines there were no small and delicate parts liable to be damaged, whether in use or when stored, and there was no reason why the bigger machin s should not be biplanes, provided they were as efficient as monoplanes aerodynamically. The question as to aerodynamic efficiency was a difficult one. It was a fact that in practice monoplanes did not as a rule achieve the efficiency which Mr. Farren had suggested. No-one would question the basis on which he had assessed that efficiency, but he (Mr. Walker) felt that if a monoplane was made to possess the same stalling speed as a biplane it would not have a 4 per cent. higher cruising speed or

top speed, if it were made for ordinary service, as in the case of a commercial aeroplane. There was a good deal of experience to support that. If one were to try to suggest a reason for that he believed it would be found in the problem of interference, which might be, and very often was, much more serious in a monoplane than in a biplane. It was the top surface of the monoplane wing that was generally interfered with, and if the flow of air over the centre section was seriously upset it would produce a drag additional to any drag which one would calculate normally from ordinary theory. That was not fundamental, and was sometimes avoided on monoplanes, but he did not think there was a case on record of a commercial or civil monoplane, even where that difficulty was avoided, giving a better performance than a biplane. When one spoke of better performance, however, there were many things to be considered, and it was rather difficult to attribute the right value to everything. One had to compare machines which had not the same stalling speed, and one had to make the correct allowance for that. If one could take the weight per horse-power in conjunction with the top speed, the top speed in relation to the stalling speed, a figure of merit could be given to practically any aeroplane, and on that basis he did not think that at present commercial monoplanes generally were equal to biplanes. There were several examples of that, and, though perhaps they were somewhat out of date, he did not think anything had occurred later to alter the facts. For instance, one might consider the early Junkers with the B.M.W. engine, and the D.H.50, which had the same horse-power, nearly the same wing area, and very nearly the same performance. The performance of the Junkers machine was not the better; indeed, it was slightly worse than that of the D.H.50. Again, the firm with which he was connected had put a monoplane wing on a known body with a known empennage, and had designed to the same landing speed; that monoplane had a substantially lower top speed. Although one could not argue the matter on examples entirely, there was a considerable number of examples which tended to show that the performance of the monoplane is not superior in any way to that of the biplane at present, so that the adoption of the monoplane was dictated generally by practical considerations.

Mr. MACKINNON WOOD: He would like to query some of the conclusions set out in the paper. Commenting on Mr. Walker's remark that there was no evidence of the monoplane having a higher cruising speed than the biplane, he recalled some experiments carried out at Farnborough, and referred to by Mr. Farren in his paper, on a small Junkers machine, which experiments showed that the pure cantilever monoplane had exactly the same lift drag curve as the Bristol Fighter. With regard to Mr. Farren's figures, it seemed rather unsatisfactory to answer the question, "Monoplane or Biplane?" in the form in which it had been answered, *i.e.*, by saying that one had 20 per cent. less paying load and 4 per cent. higher cruising speed than the other. He had wondered why Mr. Farren had done that, and it had just dawned upon him that it was because of the condition that the taking-off should be the same. He was inclined to think that Mr. Farren had stressed the taking-off condition too much. The figures in the paper showed that Monoplane C had 90 per cent. of the drag of the "Argosy." If, therefore, it were provided with engines with 90 per cent. of the power, weighing 90 per cent. of the weight and consuming 90 per cent. of the fuel, it would cruise at the same speed. Its taking-off conditions, run and climb would be roughly 10 per cent. worse. It was possible that that would be quite good enough. One would then have a biplane and a monoplane for comparison with the same cruising speed, and, with the saving in power unit and fuel in the case of the monoplane, according to Table IV. the difference in the paying load, instead of being 20 per cent., would be something under 10 per cent. To carry the argument to the same conclusion as Captain Hill had, he could not quite see why Mr. Farren had increased the weight of the

rest of the structure so much as he had; the weight of the wings had been increased from 18 to 21½ per cent., and the weight of the rest of the structure had increased nearly in the same proportion. If that were simply related to the increase in absolute tail volume, he asked if it were really necessary for the monoplane to have either a longer tail or a larger tail area than the biplane. Mr. Farren had stated in Appendix II. that he would assume that the tail volume, expressed in a certain form, had to be the same for the monoplane and the biplane. He had asked for the same slope of the pitching moment curve divided by ρSCV^2. In equation 6 one found the pitching moment depended on two terms, and the first term brought in the area and chord of the wings. It also brought in $dk_m/dk_L + h$, which was made zero by placing the centre of gravity of the monoplane at a quarter of the chord – in the biplane, further forward. If one did that, the wings made no contribution to stability, the tail was used to stabilise the fuselage, airscrew, undercarriage, etc., and the actual length and size of tail plane required was independent of the chord of the wings, whether biplane or monoplane. Possibly the nose-diving condition had something to do with the weight, and if the regulations could possibly be revised there, we might find that the weight of the rest of the structure was 18 per cent. in both cases. In that event he believed the monoplane would carry exactly the same, or very nearly the same, as the biplane, and there was nothing to choose between them. He also considered, as did Captain Hill, that it was obvious that it was not right to compare the biplane with the extreme form of monoplane, because it seemed to him that the pure cantilever monoplane must be very heavy in wing structure, and that a very little addition in external bracing would save a great deal of weight at the expense of a comparatively small increase in drag.

Captain CHADWICK: Apparently Mr. Farren had proved that the biplane was superior to the monoplane, but he had sounded rather sorry about it. A point of interest was that he had taken the structure weight of the monoplane from examples of monoplanes having an aspect ratio of about 8, but in his examples he had adopted an aspect ratio of about 5, which, of course, was not quite fair; for one thing, it increased the induced drag. He was glad that the question of load factor had been mentioned, because it had been brought home to him recently that compliance with British requirements, as contrasted with foreign requirements, necessitated a very considerable increase in structure weight, owing to the nose-diving conditions. Referring to Captain Hill's curves relating to wing weights, he said it was not very convincing to him because a great many points on the diagram were well above the biplane structure weight line.

Mr. F. HANDLEY PAGE: He agreed with Mr. Walker that the decision as to whether to build a monoplane or a biplane depended very much upon the particular requirements one had to meet. As Mr. Walker had pointed out, if one assumed the same stalling speed, one would very often come to the conclusion that the monoplane was worse than the biplane. It was interesting to note, from Mr. Farren's tables, the very high loadings that were associated with some of the monoplanes—not that he himself objected to high loadings, of course, because there were means of associating those with low landing speeds. The figures for monoplanes showed that the Fokker F.VII-3M had a wing loading of 15.8 per sq. ft., the Rohrbach "Rocco" 22.9, the Rohrbach "Roland" 17.3, and the Junkers G.31, 17.7. Was there any basic reason why a monoplane should have such a high loading? Perhaps one gained a little bit in respect of the monoplane by reason of the wing being a little nearer the ground than in the case of the biplane, leading to a little extra lift coefficient. Generally speaking, he believed that in this country biplanes mostly had been built because designs had been determined mainly from Service requirements.

Those Service requirements necessarily called for speed at height and ceiling. On the other hand, in America, for example, where civil requirements were the chief consideration, and where speed was required low down and not at heights, high loading was perhaps preferable. For those reasons there were two schools of thought emerging, a biplane school and a monoplane school, perhaps differentiated by the fact that one type was for military requirements and the other for commercial requirements. That was a point worth considering. When one examined some of the monoplane structures, however, and in particular the Junkers, one found that, although the designers had worked to the same factor of safety, there was a much greater degree of deflection on the wing structure than that which obtained in the case of an ordinary biplane wing. Apart from considering questions of load factor, and so on, one felt very much more secure, as an ordinary passenger, with the more rigid planes of the biplane as compared with the more deflected planes of the monoplane. Mr. Farren had referred to the light weights of the wing structure of the four-engined machines built by Messrs. Handley Page during the war, and had said that he (Mr. Handley Page) had upset his (Mr. Farren's) calculations. For that he was extremely sorry, but it appeared that Mr. Walker had also rather upset his calculations with regard to the "Canberra," in which case the wing weight coefficient worked out to 0.112, as against the formula weight of 0.136, which was about the same ratio, though not quite so good, as in the case of the four-engined machine. This indicated, he supposed, that the two machines were well designed, and that by looking after the material carefully, and not vastly exceeding the load factors, the constructors were able to bring the structure weight down. Referring to the dissemination of information, he urged that the more information that was published, the better it would be for aviation all round. By the proper spreading of information rapid progress was more likely to be made and the bad and the good points to be found out, so leading to better design. The paper contained some very pertinent statements on that subject, and the remarks in the opening paragraphs were very much to the point. It was interesting to note that anyone who drew a picture of the machine of the future invariably drew a picture of a monoplane; perhaps Mr. Farren would say what reasons had led him to adopt the monoplane design rather than the biplane.

Air Vice-Marshal Sir W. S. BRANCKER: He congratulated Mr. Farren on the arrangement of his paper. As a rule he could only understand at the most half of the usual paper circulated before a meeting; but on this occasion Mr. Farren had put all his plain English into the paper and kept the real scientific jam for the appendices. Of these latter he frankly confessed he could understand nothing.

He was a gentleman who preferred monoplanes, but he was quite prepared to transfer his affections to biplanes if their superiority could be proved. He was not qualified to speak from the scientific point of view, but, so far as he could understand from Professor Jones's paper delivered a week or two previously, the great hope of real progress in the design of a commercial aircraft was to develop the thick-wing monoplane.

The fact remained that since the war all the great world records had been established by monoplanes—distance, duration, speed, and all the crossings of the Atlantic. He had just been talking to Mr. Fairey, who had developed an aeroplane for the long distance record. Mr. Fairey had told him that three years ago he had confessed that he could not design an aeroplane to make a flight of 3,000 miles; now he had designed an aeroplane which he was confident would do 5,500 miles. Certain improvements had been made in the power plant during these three years, but the main gain of 20 per cent. in efficiency was due to streamlining. And the result was a monoplane.

He was more qualified to speak from the user's and the traveller's points of view. The monoplane must inevitably be cheaper to maintain than the biplane. Literally, no work could be done on the planes in the ordinary course of maintenance. The fact remained that the K.L.M. Company, which used Fokkers, claimed to be operating at 3s. 2½d. a ton-mile, all costs included. This was much cheaper than any other recorded cost of operation, and must be to some extent due to the type of aircraft used.

From the point of view of comfort, the monoplane had considerable advantages. From the high-wing monoplane the view was magnificent, and even the low-wing monoplane was much preferable to the biplane. In it the passenger had a free view above and to the side, and could see down practically as well as was the case in a biplane. The monoplane was also quieter than the biplane. Experience showed that the order of quietness to the passengers of the multi-engined machines operating from Croydon was probably as follows:—The Fokker was the best, the Rohrbach Roland next, the Junkers probably third, and the biplanes worst. Apparently the noise got bottled up in the sound box provided by the two planes, instead of getting away into the free air. On the other hand, the Fokker had proved to be the most noisy to people on the ground.

He had in the past frequently stated that 100 miles an hour was about the limit of economical cruising speed under present conditions. The need for higher speeds, however, was beginning to show itself. Already in America, where a great deal of experience in air transport had been gained, higher speeds than 100 m.p.h. were being demanded. Higher speeds were particularly necessary for mail carrying, and the Air Ministry had lately put out a specification for a mail-carrying aircraft, of which he thought the cruising speed was about 130 or 140 m.p.h.

It was interesting to see that, in the original Civil Aerial Transport Committee's Report, it was recognised that high landing speeds would have to be faced. This Committee sat in 1917 and 1918, and on it were representatives of all forms of activity, including the late Lord Northcliffe and Mr. H. G. Wells. One of the technical sub-committees definitely recommended the use of aircraft of higher landing speeds and provided with brakes for commercial use. To-day, not only could brakes be provided, but there was the automatic slot, and possibly other substitutes. With brakes and slots high landing speeds could be faced without misgivings.

The lecturer, and some of the speakers, had raised the question of the airworthiness requirement relating to the terminal nose dive. He was delighted to hear that Major Buchanan also criticised this requirement. He had always thought that the experts were wrong regarding this, but they had always proved to him that it was necessary. He was very glad that this question had been raised, and he would look into it again.

Practically all the speakers had confessed that they knew very little about monoplanes. The real cause was that in 1912 four fatal accidents to the Royal Flying Corps Military Wing occurred on monoplanes. A committee, called the "Monoplanes Accidents Committee," was assembled, and, although none of these accidents could be traced to the fact that the aircraft involved were monoplanes, the committee condemned monoplanes as being unsafe. This resulted in the monoplane being banned in the Military Wing of the Royal Flying Corps. This happened just before the war, and from that date until quite lately most designers have confined themselves entirely to the development of biplanes. As an effort towards dispelling the mist of ignorance he was endeavouring to get the Air Ministry to order two comparable experimental commercial aircraft. The specification would demand a certain performance in speed, paying load, etc., but one would be a monoplane and the other a biplane. Possibly, when

the results of operating these two aircraft under commercial conditions side by side were obtained, he would be prepared to transfer his affections to the biplane.

Mr. TROST: Of the 68 world's records recognised by the International Federation, 38 were held by monoplanes, 25 by biplanes, and 5 by a sesquiplane. Of the biplane records quite a fair proportion were held by high performance military types, but the bulk of the monoplane records were held by commercial types. The sesquiplane, holding the 5 records, might be likened more to the monoplane than to the biplane. The most interesting record of all, he considered, from the commercial point of view, was the endurance record. Of all records the pure endurance record gave the best indication of all-round commercial performance, and it was held by a monoplane. The machine constructed by Messrs. Fairey as challenger to the present record holder was also a monoplane. With regard to wing weights, as given in Mr. Farren's tables, he said that those relating to the Junkers types of machines were not strictly comparable with some of the other figures. The Junkers wings were made in parts, to facilitate transport. The G.24 and G.31 wings were made in five sections, *i.e.*, the centre section, to which the fuselage was attached, the two inner sections, and the two outer sections. In each of those sections the nine main tubular spars were connected by screw couplings, and that form of construction added considerably to the weight, not for reasons of strength, but for commercial reasons. The whole attempt at comparison simply bristled with difficulties, because of the enormous number of factors to be taken into account. Several subjects, or sub-divisions of the subject, were enumerated at the beginning of the paper, but had not yet been referred to in the course of the discussion—(1) Interest on first cost, (2) depreciation, (3) maintenance and repair, (4) insurance, and (5) housing, and each of those could form the basis for much discussion. Mr. Farren must be congratulated on having tackled the most difficult section of the subject, but the other sections might well yield effects commercially outweighing those based on Mr. Farren's interesting deductions. One great difficulty was to find sufficient machines of modern make and of similar construction for the purpose of comparison. The bulk of the monoplanes referred to in the paper were metal covered, and one could hardly compare older metal covered machines with the modern fabric biplanes. The first of those monoplanes, J.13, was of 1919 vintage, and the figures given were obtained in 1919. The total weight was 3,900 lbs., whereas the present dead weight of that machine was 5,500 lbs. The wing area of the old machine was 372 sq. ft., as compared with 505 sq. ft. in the present machine. Again, the G.24 was made in 1923, and it was the first three-engined purely commercial monoplane in the world. That might account to some extent for its relatively high wing weight. One had to remember that there was less experience available at the time of its construction than is available now.

Squadron Leader HAIG: Mr. Farren's conclusion that 20 per cent. of the pay load of a commercial biplane of the type he had dealt with would be given away if the machine were transformed into a monoplane, and there would only be in return a 4 per cent. increase in the cruising speed, was rather surprising in view of the fact that outside this country a great number of machines, and possibly the majority of them, were monoplanes. It would seem, therefore, that there was something wrong in the matter.

With regard to Mr. Farren's view that it was not possible to obtain adequate torsional stiffness in a monoplane wing without a stiff covering, he said he believed that the machine which had been referred to before that evening, the one which was about to attack the long distance record, had a fabric covered wing, and apparently there had been no trouble in this respect.

Referring to some other speakers' remarks during the discussion who said that monoplane wings flexed noticeably in the air, he (Squadron Leader Haig) had had a good deal to do with the Inflexible monoplane which had an aspect ratio of over 10/1, and on which it was known that the wing tips took up a different attitude in the air, but this was not at all apparent in flight. In fact, the wings appeared exceptionally steady.

He also said that he had to offer an apology to Mr. Farren, as, when the detail weights of the Inflexible had been asked for by the lecturer, it had not then been possible to give them. These figures were now available, and the wing weight, worked out, as in the paper on Table III., the percentage wing weight of this machine worked out at over 30 per cent. This was a penalty paid for an exaggerated aspect ratio and also to no small extent to a stiff wing covering.

Mr. DUNCANSON: He would have liked Captain Hill to have discussed a little more fully the wing section which gave practically stationary c.p., because that was the thing which most designers of cantilever monoplanes were anxious to arrive at, provided the disadvantages of that wing section were not too great. One of the main points made by Mr. Farren was that the biplane was superior to the monoplane on account of its inherent torsional stiffness. There were certain requirements which precluded the use of incidence bracing, but if that could be taken into account he believed it would result in still lighter biplane structures. One was reminded that there was no real criterion of the torsional stiffness of any aeroplane wing, either monoplane or biplane, and what was wanted was a definite ruling as to how stiff torsionally a monoplane should be. Some months ago he had started to make a mathematical analysis of the structural weights of the cantilever monoplane, and had arrived at some extraordinary results. He had found that if one put the material in the right place all along the wing one could produce a wing with a structural weight very much less than that of any wing that had ever been made; one could reduce it to less than 10 per cent. of the total weight simply by placing the material in the right place. The reason was that in biplane structures a large proportion of the material was not being used at its maximum stress, whereas in the monoplane it was a much easier engineering problem, because the whole thing was a cantilever, to get the whole of the material working at its maximum capacity. For that reason the cantilever monoplane had a big future. The only problem to be faced was that of deciding what its torsional rigidity should be. That provision of the proper torsional rigidity would in itself cause the weight to be increased, but until some ruling was laid down we did not know how much. With regard to cruising speeds, his opinion was that they should be increased. One possibility, of course, was to cruise at higher altitudes with super-charged engines—if the passengers would stand it.

Mr. H. STIEGER: After reading Mr. Farren's paper he could not help feeling that Mr. Farren started with his conclusion and then wrote the lecture to prove it. Theoretically one can prove anything; it depends just on the assumptions. These may be right in one particular case, but the result may be thoroughly wrong if any attempt is made to generalise it.

For comparison, the lecturer chose the Argosy and arrived at a definite conclusion, damning all monoplanes of that class. Further, he generalises that for a bigger range this monoplane is even worse off. That may be right according to the formula—but what about all the long range monoplanes?

The two basic assumptions for the comparison are: The monoplane *must* have the same stalling speed as the biplane and the monoplane *must* have the same total resistance under take-off conditions as the biplane. The result is, on

one side a perfectly good biplane and on the other side a monoplane that nobody would ever dream to build. Compare Figs. 1, 2, 3, with Figs. 9 and 10.

Obviously the aspect ratio depends on wing weight and fuel consumption for a given range and wing loading, but the wing weight also varies with the aspect ratio.

As the comparison is based on fuel consumption and non-paying load, it is not fair to take for the monoplane the fuel consumption with an aspect ratio of 4.5 or 5 to 1 and afterwards, for the wing weight, a Junker or B.F.W. wing with aspect ratios of 8 or 10 to 1.

The complete Fokker F.VII. wing is 16.2 per cent. with a wing loading of 16.5 lbs./sq. ft. Reducing the load to 12 lbs./sq. ft. increases the weight to 22 per cent., but also increases the factor by 37.5 per cent. Therefore the weight figure given in Table IV. for a monoplane wing corresponds to a much stronger wing with a much bigger aspect ratio.

Personally, he believed the question monoplane or biplane depends very much on the type and purpose of a machine and also on the working conditions, the aerodromes, etc. There is room for both, as they have both their own fields, but it does not seem fair to disfigure one of them till it can hardly be recognised and then compare it with the other. As far as the Argosy is concerned, a monoplane appears to have quite a good chance, and if one goes to 40,000 lbs. all-up weight or to flying boats even bigger, it seems doubtful if the biplane has much of a chance.

He did not think the maximum lift coefficient was so extremely important, although it may be possible in certain cases to get up to 0.75 and 0.8 in full scale. Fokker and other machines cannot even make use of it for landing. There are other considerations such as minimum drag, C.P. shift, etc., coming in.

In Table IV. the lecturer increased the weight figure for the Junker wing to allow for the wing structure through the body, but has he afterwards deducted that amount from the " rest of structure "? It does not seem so. It amounts really to the heaviest wing of one machine, increased by an appreciable percentage for the bigger area in spite of reduction of aspect ratio and wing loading, plus the heaviest " rest of structure " from another machine to represent the average monoplane.

In Table V. the lecturer gives the specifications for two machines, 28,000 lbs. all up. It is to be hoped no one will ever build this monoplane. If one takes a good biplane and puts a single wing on, then it is bound to be a bad monoplane.

If for a definite purpose type of machine, as here in Table V, one wants to decide whether monoplane or biplane, a fair base for comparison would seem to be as follows:—Both machines have to land in and get out of a certain field, they must have the same load factors, they must carry the same paying load, and then the question is simply how fast do they go and how much does it cost?

The size of this field corresponds to the amount of safety required in case of forced landings, or flying in fog or night.

The lecturer is doubtful whether adequate torsional stiffness can be obtained except by use of stiff covering. Personally he thought it was possible to make a very stiff wing, to prevent any flutter or loss in lateral control, without stiff covering. It was even possible to make it stiff enough for comparatively very little torsional strength and therefore very little weight.

The lecturer thinks that for the monoplane with a large chord the covering or internal bracing must be heavier; that is only true if one designs a thick wing the same way as a thin biplane wing, which is not reasonable.

He did not think the Junker construction was very efficient. It is heavier than the Fokker, which is all wood. If Junker could make full use of his more

efficient material, steel and duraluminium, his structure ought to be much lighter than a wooden one.

Squadron Leader ENGLAND: The machines considered were not truly comparable, as those taking part in the discussion had already pointed out, owing to the fact that some were designed and put into service during the latter stages of the war whilst others had been designed and put into service during the past 18 months. He suggested to Mr. Farren that a comparison of the monoplanes and biplanes which participated in the Lympne Meeting of 1924 might prove interesting, in that all machines taking part were designed primarily for the competition, having engines of approximately the same type or h.p. On conclusion of the meeting most of the machines migrated to Martlesham, so that it was possible to hold an unofficial light plane competition. Unfortunately, owing to various causes, the competition dragged out for a number of months, and also for other diverse reasons, some machines never completed their tests. Nevertheless, he had a very clear recollection that opinions favoured the biplanes, in that they were handier, and for all-round performance the biplane appeared to be the better.

Admittedly, since that date the monoplane had been considerably improved, but even now he was of opinion that for equal weight and h.p. the biplane was more manœuvrable than the monoplane.

Mr. BRAMSON: Commenting on the reference made by Sir Sefton Brancker to the fact that practice in America was tending more towards high power and cruising speeds, he pointed out that unless aeroplanes of all sorts could be improved very much indeed, that tendency would mean higher landing speeds. That consideration led one to consider the reason for the craze for low landing speeds. The origin of it, he believed, was the fear of crashing. If one were sure of being able always to land on an aerodrome there was no particular need for a low landing speed, and, therefore, the question of performance was again brought into close relationship with that of safety. Apparently the German and other Continental designers had adopted the view that if one were sure of landing always on a good aerodrome there was no particular reason for a low landing speed. It was not only the landing speed that was affected, however, but also the take-off. Apparently the limiting consideration would not be so much the stalling speed as the length of take-off. Expressing his disagreement with Mr. Trost's suggestion that the most significant world's record was the endurance record, he said that an aeroplane could get into the air and might travel at only 50 miles per hour, but would achieve the endurance record if it stayed long enough in the air. The test which in his view brought out all the desirable qualities of a commercial aeroplane was the long distance test, because it embodied speed, carrying capacity, and fuel economy. Finally, Mr. Bramson drew attention to a lecture delivered to the Society on January 10th by Professor Melvill Jones on the streamline aeroplane, and referred to it as one of the most valuable delivered to the Society. In the course of that lecture, Professor Jones had put forward a criterion in the light of which aeroplane performance could be judged, and it had been shown that the average aeroplane of to-day has about $2\frac{1}{2}$ times the drag that it need have theoretically. The conclusion to which that lecture had led, as he had understood it, was that if real progress were to be achieved we must do away with parasitic drag, and it was difficult to see how to do that except by producing very clean monoplanes.

Captain BARNWELL: Why was it that all seemed to fear that they would be considered "unimaginative" or "reactionary" unless they suggested that the huge unbraced monoplane is the machine of the future? Mr. Farren's written paper appears to show that for large machines the biplane is definitely better than the monoplane, and one feels pretty sure that many who have

tried, like him, to work out the case impartially from reasonable data, have come to the same conclusions—so why not have the courage of one's conclusions.

Surely the most useful and enlightening method of conducting an enquiry into any engineering problem is to start with an outlook truly unbiassed, to collect data with due discrimination, and then, by logical mathematical processes, to attempt the estimation of probabilities, possibilities and impossibilities?

Mr. Farren deserves thanks for his effort to enliven and stimulate the imaginations by showing slides of machines of the future as per his own imagination: but why monoplanes, unless Mr. Farren wishes to "hedge"?

Personally he (Captain Barnwell) had no use for the "what *looks* right is *right*" type of argument in engineering; it is logically meaningless. He did not therefore regard with any particular interest or respect sketches of enormous flying-fish type of aeroplanes, the reason for these sketches being, presumably, that the sketcher thinks it "looks right," or wishes to show imagination.

From such reliable data as he could come by, and using methods of estimation which are, he thought, reasonably accurate for comparative purposes, he found that for aeroplanes of the same total weight, *same strength and same stalling speed,* the structure of a monoplane (with no external bracing) is about 30 per cent. greater than that of a biplane (with normal external bracing): by structure being meant wings, fuselage and tail element.

Now for a biplane of 15,000 lbs. a normal figure for this structure weight would be about 3,100 lbs., whilst for one of 40,000 lbs. it would be about 12,000 lbs. Hence, for a monoplane of 15,000 lbs. the structure would be about 900 lbs. (6 per cent. W_T) heavier than that of a biplane, for a monoplane of 40,000 lbs. the structure would be about 3,600 lbs. (9 per cent. W_T) heavier than that of a biplane: these figures represent extra load that the biplane can carry.

If, however, the monoplane has a lower drag than the biplane (at the same required cruising speed) and hence burns less fuel per mile, then the value of the decrease of weight of fuel and tanks (for some desired length of flight may be added to the load the *monoplane* can carry.

Now, the drag of the external bracing of a biplane can, and will be, materially reduced in the future. All end fittings must be kept inside the wing covering; there seems no logical reason for complaining even if they be rendered thereby somewhat inaccessible, for, after all, every joint in the structure of a monoplane is entirely inaccessible. Again, in large machines, surely one may expect to use eventually members of real "streamline" form for the external tension bracing?

To quote figures for existing machines is doubtful argument, and more often than not, entirely misleading, but he was tempted to do so because this line of argument is often used to prove how some particular monoplane is superior to some particular biplane:—

From the official figures for the National Air Tour of 1928 held in U.S.A.

Machine.	B.H.P.	Load carried.	Top speed.	Take-off time.
(1) Waco 10	220	950	128.1	5.1
(2) Stinson Detroiter ...	220	2098	118.8	15.3
(3) Ryan	220	1256	115.5	13.3
(4) Bellanca	220	1794	125.3	14.5
(5) Lockhead	220	1403	135.9	11.9
(6) Fairchild	220	1368	113.4	13.5
(7) Buhl	220	1420	136.7	12.8

No. (1) is an open cockpit biplane with external bracing, obviously underloaded compared to the others. (Note its take-off time).

Nos. (2), (3), (4) and (6) are the fashionable strut-braced monoplanes with cabin bodies.

No. (5) is a cabin bodied monoplane with no external bracing.

No. (7) is a cabin bodied biplane with external bracing.

It should be noted that 2 Stinson Detroiters, 3 Ryans and 2 Bellancas took part in the competition, hence *mean* figures for these machines have been given; further, all the machines here quoted had the same engine.

It would appear, from these results, that the biplane is not of higher drag than the monoplane.

For large aeroplanes, then, he did not believe that the saving (if any) in fuel and tanks weight for the monoplane will compensate for its greater structural weight, with the possible exception of a duration of flight so great as to render the machine a poor " pay load " proposition in any case.

It appears futile to argue that in order to improve the case for the monoplane stalling speeds must be allowed to go up and the terminal dive case abolished.

Raising the stalling speed helps the biplane just as much as it does the monoplane; abolition of the terminal nose dive case also helps the biplane (though not to the same extent as it does the monoplane) and, if one honestly has believed it to be a reasonable case in the past, has one any justifiable arguments for throwing it overboard because it shows up a particular disposition of material?

One is interested in Mr. Farren's equation for percentage weight of the wing structure of biplanes: it appears to give reasonable values, though on the high side for present day practice; but surely the equation is incorrect in its physical dimensions?

Regarding his table of wing weights for monoplanes, one feels able to accept without reserve only about six of these. Those that one feels most uneasy about are all " makers' figures," and one feels somewhat politely sceptical. One feels most politely sceptical about those for the Dornier E.

To start with, there is something wrong with the table, in that figures for weight, wing area and wing loading do not tally. However, assuming wing area and wing loading be taken as correct and the total weight therefore as only 80,000 lbs. instead of the 113,000 lbs. quoted, he still found it very hard to believe that the weight of wings is only 14½ per cent. of the total weight. He estimated that 20 per cent. would be a minimum value.

Mr. Farren deals wisely with the subject of wing torsional properties. This is a matter of great complexity, so is apt to be ignored, but it is of very real importance and is certainly a point in which the biplane is superior to the monoplane.

One is left then with the feeling that for *large* aeroplanes, at least, the biplane is preferable to the monoplane, unless (and this is, of course, an important proviso) there be definite operational requirements which are met better by the monoplane.

Mr. H. DAVIES: If one ignores for the moment the question of manœuvrability and general suitability for military purposes, the crux of the matter is this: The monoplane suffers from a disadvantage as regards structural weight—the biplane as regards drag. The weight of the monoplane structure is a difficulty which the skill of the designer can overcome. But the drag of the biplane can best be described as an act of God. It is inherent in the biplane structure.

In the following brief analysis an attempt is made to illustrate the disadvantage from which the biplane suffers. The analysis is necessarily very rough, but will serve its purpose.

Consider three types of aircraft:—

1. The Single-Seater Fighter.
   V_{max} (top speed) approximately 160 m.p.h.
   W (all-up weight) approximately 3,000 lbs.
2. The Bomber.
   V_{max} 125 m.p.h.
   W 10,000 lbs.
3. The large Passenger Machine or Troop Carrier.
   V_{max} 105 m.p.h.
   W 30,000 lbs.

Assume a wing loading of 10 lbs. per sq. ft. in all the above cases. The following figures are of general application:—

(*a*) For a monoplane of aspect ratio 6,
$$k_D = k_{D0} + 0.111\ k_L^2.$$

(*b*) For a biplane of aspect ratio 6, of equal plane areas, and with a gap-chord ratio of unity,
$$k_D = k_{D0} + 0.168\ k_L^2.$$

(*c*) For any normal biplane, the following approximation gives a rough idea of the drag of the external wing bracing,
$$k_D \text{ (struts and wires)} = 0.0018.$$

Equations (*a*) and (*b*) have a theoretical foundation and are taken from "Glauert" (pp. 149 and 188), while (*c*) is purely empirical. From examination of a number of cases (*c*) is fairly constant for any weight of aircraft. All three types of aircraft, 1, 2 and 3, are to be considered as monoplanes or biplanes. The monoplane structure which one favours is of the semi-cantilever variety, with tapering wings. Both the wing taper and the external strut bracing reduce the weight of the wings very materially, while the parasitic drag of the wing bracing is very small. This point will be returned to later.

Type 1, the Single-Seater Fighter.

For both monoplane and biplane, the same plane loading and the same top speed are assumed. Hence, at top speed the value of k_L is the same in both cases. The extra drag inherent in the biplane structure (and due to the mutual interference of the wings) is given by:—

$$\text{Interference drag} = (0.057\ k_L^2)\ \rho S V^2$$
$$= 0.057\ k_L \times W$$

(This is the quantity which is previously referred to as the act of God.)

Now $V_{max} = 160$ m.p.h. $= 235$ ft./sec.

$\therefore\ k_L = W / \rho S V^2 = 10 / \{ 0.00237 \times (235)^2 \} = 0.0766.$

$\therefore$ Interference drag $= 0.057 \times 0.0766 \times 3000 = 13.1$ lbs. (at top speed).

Next, with reference to the external wing bracing: The drag of the wing bracing struts is small in a semi-cantilever monoplane, in comparison with the external wing bracing of a normal biplane; and it seems reasonable to assume that at least two-thirds of the strut and wire drag of the biplane is saved in the semi-cantilever monoplane. In other words, the saving is represented by:—

$$\tfrac{2}{3} \times 0.0018 \times \rho S\ (V_{max})^2$$
$$= 0.0012 \times W / k_L$$
$$= 0.0012 \times 3000 / 0.0766$$
$$= 47 \text{ lbs. (at top speed).}$$

Total saving in drag at top speed by the use of the monoplane = 13 + 47 = 60 lbs.

Effective h.p. saved = (60 × 235)/550 = 25.6.

True saving in b.h.p. (assuming 80 per cent. airscrew efficiency) = 1.25 × 25.6 = 32.

With a Jaguar engine of approximately 425 h.p., this amounts to a saving of 7.5 per cent.

The same (admittedly) rough and ready treatment to types 2 and 3 will now be applied.

Type 2, the Bomber.

$$\text{Interference drag} = 0.057\, k_L \times W$$

$$V_{max} = 125 \text{ m.p.h.} = 183 \text{ ft./sec.}$$

$$\therefore\ k_L = W/\rho S\,(V_{max})^2 = 10/\{\,0.00237 \times (183)^2\,\} = 0.1255.$$

$$\therefore\ \text{Interference drag} = 0.057 \times 0.1255 \times 10{,}000 = 71.6 \text{ lbs. (at top speed).}$$

$$\text{Saving in strut and wire drag} = 0.0012 \times W/k_L = 0.0012 \times (10{,}000/0.1255) = 95.7 \text{ lbs. (at top speed).}$$

$$\text{Total drag saved by semi-cantilever monoplane} = 167 \text{ lbs.}$$

$$\text{B.H.P. saved} = 1.25 \times (167 \times 183)/550 = 69.5.$$

Assuming 850 h.p. to be available, the saving amounts to 8.2 per cent.

Type 3, the large Passenger Machine or Troop Carrier.

$$\text{Interference drag} = 0.057\, k_L \times W.$$

$$V_{max} = 105 \text{ m.p.h.} = 154 \text{ ft./sec.}$$

$$k_L = W/\rho S\,(V_{max})^2 = 10/\{\,0.00237 \times (154)^2\,\} = 0.178.$$

$$\therefore\ \text{Interference drag} = 0.057 \times 0.178 \times 30{,}000 = 304 \text{ lbs.}$$

$$\text{Saving in strut and wire drag} = 0.0012 \times (30{,}000/0.178) = 202 \text{ lbs.}$$

$$\text{Total drag saved by semi-cantilever monoplane} = 506 \text{ lbs.}$$

$$\text{B.H.P. saved} = 1.25 \times (506 \times 154/550) = 177.$$

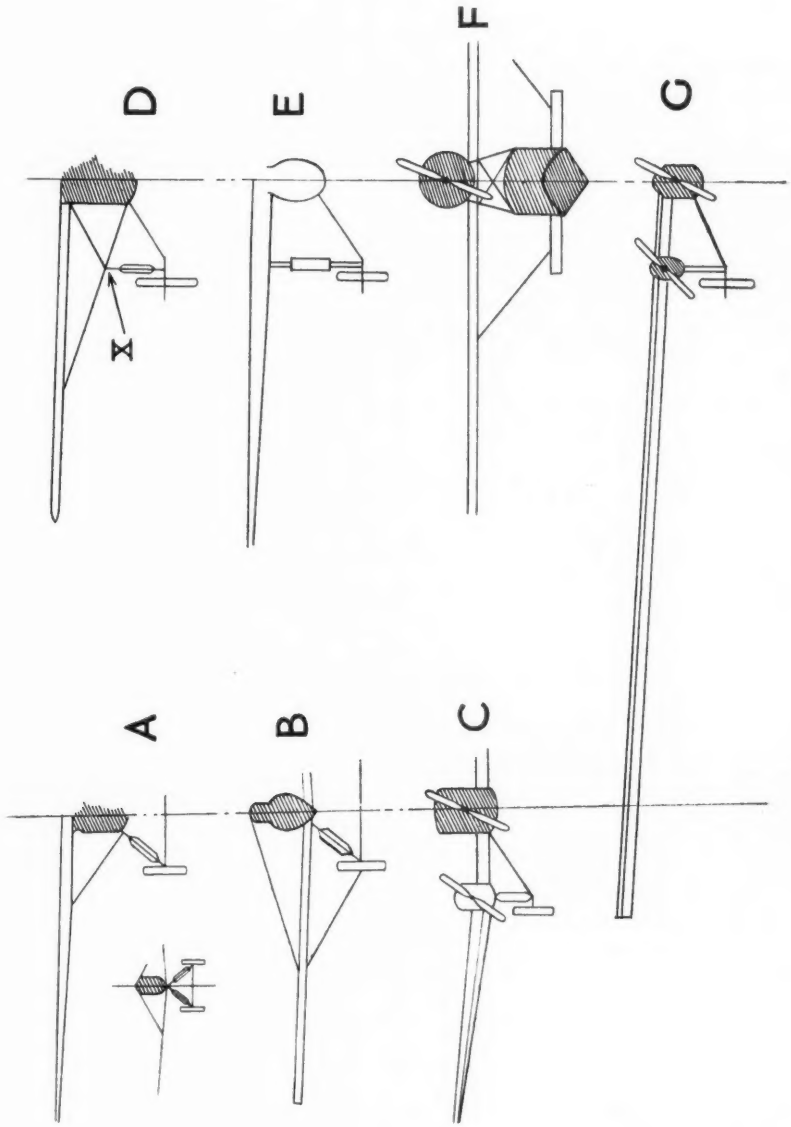
This is probably about 10 per cent. of the b.h.p. available.

A feature which emerges from the foregoing analysis is the growth, with increase of all-up weight, of the power dissipated in overcoming the mutual interference of the planes. For the smaller aircraft this is not such an important item, and the biplane loses chiefly in virtue of its external bracing. For every type of aircraft, however, the wastefulness of the biplane is apparent.

The excessive loss of power, due to mutual wing interference in the heavier craft, may help to explain the choice of a suitable monoplane construction for machines like the Junker's passenger carrier and the Fairey long-distance aeroplane. These are both pure cantilever monoplanes, with wings that taper both in chord and thickness along practically the entire span. The extreme depth of the wing at its root allows for the storage of fuel, which could hardly be accommodated (in the case of the Fairey machine) in the very attenuated fuselage. A semi-cantilever wing would not have been equally capacious, though I think it would have effected a very considerable saving in structure weight.

As regards structure weight, the monoplane is at a disadvantage, although this disadvantage in a suitably designed monoplane is less than a great many people seem to imagine. Certain conventional types of monoplane are indicated below, and he thought that from considerations of structural weight (combined with aerodynamic efficiency) type A is to be preferred.

Type A is represented by the Westland Widgeon, and in the low wing form (inset) by the Parnall Pixie and the D.H.53.


D
E
F
G
A
B
C

Type B is represented by the Tiger Moth. The bracing, of course, is similar to that of the S.5. He thought the type to be unsuited to a fighting aircraft, in view of the danger of shot wires.

Type C is the typical German commercial aircraft. The wing structure is somewhat heavy, the load factors are smaller than those demanded by the Air Ministry, and the landing speed is rather high.

Type D is similar to the "Spirit of St. Louis," and it has numerous representatives in this country. The long lift struts are stabilised at point X, which offers a suitable point of attachment for the oleo leg. The type is adapted to the use of a split axle with a conveniently wide track. The structure weight is greatly reduced by the relatively small overhang, the conditions of spar loading being similar to those of a biplane. There is no necessity for wing taper, which means that every rib can be made alike—a very considerable advantage from a commercial point of view. The external bracing, however, offered more drag than any other type of monoplane that he had illustrated.

E is a pure cantilever monoplane, in which landing loads are resisted by the wing structure. The Fokker and the Fairey long-distance aircraft are instances of the type.

F is a crude representation of a small Dornier Wal, with a single Jupiter engine. The lower sub-planes give very slight lift, and are fitted to provide a platform for passengers—and also to obviate the use of wing-tip floats, by providing considerable lateral stability on the water. Type F is therefore to all intents and purposes a monoplane, and is really a modification of type A.

Type G is an attempt to achieve an aerodynamic ideal, regardless of structural or any other considerations. This aircraft made its début in public at the Hendon Air Display of 1928. Model tests in the wind tunnel show an exceptionally high value of L/D. The full-scale performance may be summarised, however, in the following rather brutal manner:—

(*a*) No useful load.
(*b*) Practically no speed range.

This concludes a very brief and cursory survey of the general question. He would like to forestall possible criticisms.

A high aspect ratio is supposed to be much easier of attainment with a biplane than a monoplane structure. This would lead to a gain in aerodynamic efficiency which would partially offset the losses due to wing bracing and plane interference. Examination of a large number of monoplanes and biplanes reveals the fact that the average biplane does not actually possess a higher aspect ratio than the average monoplane. In particular, it has been found possible to construct a pure cantilever monoplane, such as the Fairey long-distance machine, with a mean aspect ratio of 7·5.

The weight of the monoplane wing structure is supposed to be a disadvantage, though in a suitably designed monoplane (that is to say, type A or type B) it is a very slight disadvantage. In this respect the monoplane has everything to gain from certain new developments, such as the use of magnesium alloy for the spars, and the use of slots for the purpose of reducing the total wing area while maintaining a reasonable landing speed. Both of these fields remain to be fully explored and he believed that they will help to settle the question of comparative merit in favour of the monoplane.

Reply to Discussion

Mr. Farren, replying to the discussion, said he found himself unable to agree with Captain Hill's treatment of the point he had raised. He was sorry if Captain Hill had found the tables of figures confusing, but the question was not a simple one. Professor Jones had read the paper, and he also had asked why the figures in the table could not be represented on a curve. The answer was that they involved several independent variables, as he had tried to show in Appendix III. He wished now that he had not drawn the curve (Fig. 4) at all. For the machines in Tables II. and III. wing loading, span in both directions (span and chord) and load factor all varied. One needed at least five co-ordinates to represent everything. To do as Captain Hill had done was to obscure the whole issue and he could not agree that one could make any safe deduction from Captain Hill's diagram. It might be that the monoplanes of Figs. 1, 2 and 3 were not as good as could be designed, but he thought that Captain Hill had produced no evidence to show that, for example, by adopting the type of monoplane he favoured there would be an appreciable improvement. The claim he (the lecturer) made was that on the assumptions he had made the machine of Figs. 1, 2 and 3 could be legitimately regarded as *comparable*. They had the same standards of strength, the same endurance, they used the same engines and were of the same total weight; they had the same criteria, as nearly as he could give it them, of stability and control, and the same take-off; they had the same value for stalling speed. One could adopt a high or a low landing speed, but it must be the same for both. He believed it was generally recognised that aeroplane design started with stalling speed. Whatever the stalling speed anyone liked to name, he was ready to outline a comparable monoplane and biplane on that basis. His paper was designed to show that if one did that, and kept to the rules, one would come to the conclusion he had suggested in respect of machines *of the type he had dealt with*. He agreed, and he believed all agreed, with regard to the terminal velocity dive. He did not know to what extent we were compromised by the I.C.A.N., but any relaxation of the present requirements would make it definitely easier for the monoplane, for the success of which there was needed a wing which had a high maximum lift coefficient, and hence a high moment coefficient.

He agreed with Mr. Walker that there were many practical matters to be considered in deciding between monoplane and biplane, and had hoped that someone would have discussed them. Hardly anyone, however, had even referred to the other considerations which, as he had tried to make plain at the beginning of the paper, may be at least as important as the purely technical ones he had dealt with. Sir Sefton Brancker had intimated that it was cheaper to adjust the wings of the Junkers than of a conventional biplane "because you can't". One might add that it was rather awkward if one happened to want to.

It had been suggested by Major Buchanan, Mr. MacKinnon Wood and Mr. Chadwick that he (Mr. Farren) had not the courage of his convictions. He was not aware that he had any "convictions" in such a matter as this. He had arrived at certain *conclusions*, after a fairly wide experience and considerable thought, as he hoped the paper made clear. But many of the conditions on which his line of argument was based were likely to change as aviation developed, and his conclusions might then need to be modified. He had deliberately taken

a favourable view of those characteristics of a monoplane in which he was inexperienced. If in spite of this he could establish that, for the type of aeroplane he had considered, the biplane was to an appreciable extent superior to the monoplane, as he believed he had done, he was on fairly safe ground. Mr MacKinnon Wood, with other speakers, was troubled as to why he had allowed the cruising speed of the monoplane to rise, and had given the solution, which was indicated also in the paper, namely, that the take-off had to be maintained at the same level. Presuming that one accepted his (Mr. Farren's) suggestions as to safety, and particularly that with regard to stalling speed, if one then fixed the total weight of the aeroplane and the range in air miles at some definite fraction of the maximum engine power, one knew then that the engines would wear out at the same rate. If in one case the engines were throttled more than in the other, one could not say how much less rapidly the more throttled engines would wear out. It was important to estimate on the basis of keeping constant the things which were most difficult to estimate, so long as the result was not obviously misleading. He had chosen to arrange for the engines in each case to have the same life, because that was a crucial point in commercial aeronautics. The inevitable result then was that the difference between the two types of machine appeared on the one hand as a difference in paying load, and on the other a difference in cruising speed. The monoplane he had dealt with—he had chosen monoplane C as a reasonably representative monoplane for comparison—had 4 per cent. higher cruising speed than the equivalent biplane. One must decide to what extent one was prepared to regard that as an advantage. It might not be easy to decide how much more one could earn in the way of dividends on a commercial air service by reason of the fact that the machines used could go 4 or 5 per cent. faster than others, everything else being equal, but presumably there was some advantage. At any rate, the fuel consumed was reduced by at least that amount. It was easy to decide how much one would suffer by reason of a reduction in paying load.

With regard to Mr. Chadwick's remarks on aspect ratio, he had pointed out in the paper that the term might with advantage be abandoned in such connections as this. What mattered was the weight that was carried, in relation to the *span*. The aeroplanes he had outlined had the right span loading (weight/span^2) to produce the same take-off. The fact that their aspect ratio was small was no disadvantage, so far as he understood it; he saw no reason why it should not be small. The German machines had a larger aspect ratio because they had a very small wing *area*.

Dealing with Mr. Wood's remarks on the question of tail volume, he pointed out that the tail volume of monoplanes such as the Junkers and Fokkers was generally in excess of that of normal British aeroplanes. He had adopted a basis which, so far as he could see, was worked to fairly generally both for monoplanes and biplanes. In Table I. the tail areas of monoplanes B and C were in fact considerably less than that of the biplane. It might perhaps be worth noting, in connection with Figs. 1, 2 and 3, that the biplane was fitted with a biplane tail.

He could not quite understand Sir Sefton Brancker's reasons for saying that a biplane was more noisy than a monoplane because it had two wings. The noise they created was a great trouble with aeroplanes at present, but he did not believe there could be an essential difference between the monoplane and the biplane in this respect.

He disagreed with Mr. Trost's opinion with regard to records. It seemed to him that records, being 90 per cent. pure publicity, were not a safe basis

to take in deciding such a question as this. The gaining of most records depended mainly upon the size of the aerodrome, the strength of the undercarriage and the courage of the pilot.

As to the comparison between metal-covered and fabric-covered wings, his experience was that fabric lasted a very long time. He would not be surprised to find that it lasted longer than some metal coverings.

Commenting on Squadron Leader Haig's suggestion that the majority of aeroplanes outside this country were monoplanes, he said that in connection with the writing of an article on aeroplanes for the *Encyclopædia Britannica* he had analysed the types of machines, and had found that as a matter of fact the number of biplanes was considerably in excess of the number of monoplanes. He could quite believe that the " Inflexible " wing did not vibrate when in flight. Presumably it took up a permanent deflection, however, as the machine went into the air. No harm would result from that; everything deflected when loaded. But a certain degree of torsional stiffness of wing structures was essential, and here the monoplane was at some disadvantage.

He thought that Mr. Duncanson had put his finger on a crucial point. He (Mr. Farren) had a great admiration for the Junkers construction, and had come to the conclusion that Dr. Junkers had evolved a system which had no superior. He had realised that torsional stiffness was an essential feature in a monoplane wing. He had made it torsionally stiff by the only method he had found to be satisfactory, and everyone had followed his example since, in some degree, by covering either the whole or a part of the wing with some form of stiff sheet.

Mr. Stieger had devised an ingenious method of overcoming the trouble, and it was to be hoped that it would be successful, but its development had not yet reached the stage at which definite proof was forthcoming. With regard to the lower wing weight of the Fokker F.VII., as shown in Table IV., which was in a sense the crucial table, he pointed out that the Fokker machine had a span materially less than that of the other machines of which particulars were given there, and he had included it merely for purposes of illustration. The weight of the wings of monoplanes appeared to increase with span in much the same way as did the weight of the wings of biplanes, and it followed, therefore, that the percentage wing weight would be increased if the span of the Fokker machine were similar to that of the " Argosy." For reasons he had already referred to in the discussion, the wing area would need to be increased, and it was also necessary logically to provide the machine with the appropriate amount of control surfaces, and so on. If a long fuselage were not used, he believed it would be found that, for reasons explained in the appendices, larger control surfaces would be necessary, and the weight would not be materially less in the case of the other machines.

The suggestion made by Squadron Leader England was interesting, but unfortunately the machines concerned were all small ones, and he (Mr. Farren) was of the opinion that there was no one answer to the question " Monoplane or Biplane?" which applied to all sizes of aeroplane.

In reply to Mr. Bramson, he said that German aeroplane design seemed to have been based on the assumption that the machines would always land on extremely good aerodromes, and many of them had a stalling speed of 70 miles an hour, or something like it. Unfortunately, however, they did not always land on the good aerodromes which were provided, and when they landed elsewhere they often had to pay the penalty of high landing speeds. He felt quite sure that if we based our civil aviation development on speed and not on safety

it would not help us. Commenting on Mr. Bramson's remarks as to Professor Jones' paper, Mr. Farren said he wished Professor Jones had been able to be present to deal with the points raised, but from his own point of view he would point out that whereas his (Mr. Farren's) paper was concerned with an immediate problem of aeroplane design, involving the usual compromise between all the relevant considerations, Professor Jones' paper dealt with one aspect of aeroplane development only—reduction of resistance, and its consequences. The fact that the lines on which aeroplanes might develop in the future were not quite the same as those which, for economic reasons, must be followed in the construction of aeroplanes to-day was hardly surprising.

In further reply to the discussion and to the written contributions of members:—

Captain Hill's table of comparative dimensions exhibits clearly the result of the misconception underlying his diagram. Adopting a wing percentage weight of 18 for the biplane of 89 ft. span, he allows 18.5 per cent. only for that of a monoplane of 106 ft. span. I do not think there is anything to justify such a figure either in my paper, or in Captain Hill's diagram, or in his contribution.

Mr. Wood raises the question (also mentioned by others) of the increase in the weight of the rest of the structure used in Table IV. The basis of my figures is given on the page facing this table. Using a more detailed analysis of the weight of the structure of the three chief machines than is given in the paper, an estimate was made of the amounts by which the relevant parts would need to be increased in order to allow for increase in relative size or in strength. Broadly speaking, the increase is due chiefly to the large chord of the wing (*which existing monoplanes avoid by a consistent indifference to stalling speed*) requiring a longer and deeper body; and to the larger tail (and hence body and wing structure) loads arising from the high moment coefficient of the high lift wing. A lower lift wing would mean a still larger chord and probably little difference in the result.

In regard to the take-off, I do not agree that anything less than that taken as a standard is acceptable in these days The same aerodynamic condition governs the ability to fly with one engine stopped. For a very high speed machine take-off ceases to be a criterion as is pointed out at the end of the paper—see Table V.—and for such a machine one arrives at the same conclusion as Mr. Wood does—there is little or nothing between the two types.

He (Mr. Farren) was not impressed by the " partially braced " monoplane structure. The only rational explanation of the light weight of the Fokker construction is that it avoids joints (in this connection see Mr. Trost's remarks). As soon as very highly loaded struts are used the design begins to lose its economical character mainly because of the weight of joints. To say that such an arrangement " saves a good deal of weight at the expense of a little extra drag " is in the writer's view to beg the question.

Mr. Handley Page asks why, in the lantern slides (not reproduced) with which the lecture was prefaced, the machine of the far future was shown as a monoplane. The answer is, the greater simplicity and neatness of the result—when one is not concerned with designing or building it or making it pay!

Mr. Stieger reads too much into the paper, and ascribes generalisations which were carefully avoided. Like others who contributed to the discussion, he appears to assign a significance to the term " aspect ratio " to which it has no real claim. The monoplanes and biplane of Figs. 1, 2 and 3 are demonstrably equivalent aerodynamically at take-off. They have the same climb with the same engines and the same weight. At cruising speed the monoplane (for the

same power) is appreciably faster. They have the same strength and stalling speed. The monoplanes structures are, however, *heavier* and their extra structure weight (as estimated) *and consequent fall in paying load* outweighs the gain in speed. Of what does Mr. Stieger complain? No " formula " has been suggested by which aeroplanes can be compared. No predilection for any one type is put forward. The writer has had a great deal of experience of biplane design and has studied as carefully as he was able the monoplane, as an alternative, and *for the size and type of aeroplane with which alone this paper is concerned*, the conclusion has been arrived at that the biplane is a better proposition, when all considerations are taken into account. Here not only those technical matters are referred to which are dealt with at length, as far as possible, in my paper, but also to others which have been enumerated. Upon the latter no pretension to be an authority is put forward by the author, and they have therefore not been discussed. But conclusions have been reached upon them, based upon information which is regarded as trustworthy.

This conclusion had certainly been reached, on all counts, by the author, before the paper was written. The paper was written, not to *prove* anything, but to set out the reasons for the conclusions arrived at. Why does Mr. Stieger consider one unduly conservative or prejudiced because one's own study of a problem leads one to a conclusion which differs from his own?

Captain Barnwell has pointed out an error (which is now corrected) in Table III. concerning the Dornier E. According to Dr. Dornier's paper (December, 1928) the weights are as given originally, but the wing dimensions (Dr. Dornier gave only the area) were incorrect and should be as now printed. The 140 ft. span is a pure guess—it may be 180 ft. One agrees with Captain Barnwell that the figures concerning the Dornier machines are very difficult to reconcile with British experience, but personally the explanation appears to lie in the very high loading and different strength specifications.

Captain Barnwell may be assured that there is no desire to hedge. The conclusions are what have been stated and (like a certain statesman) it was not known how sound they were till the counter-arguments of those who differ were read.

Perhaps, as Captain Barnwell suggests, it would have been better to read the paper more fully. At least one would not then have felt—as on reading the discussion one has felt—that some of the most enthusiastic critics have not paid the compliment that must perforce be paid to them by the author.

Captain Barnwell suggests that there is some reason to suspect the weight figures given by manufacturers. Weights, if obtained from responsible members of a firm, and not merely at second or third hand, are generally reliable. Load factors, stalling speeds, engine power and consumption, are in a different category. They depend on methods of calculation, specification and measurement. But weight is the same (to a sufficient approximation) all the world over, and is easy to measure.

The difficulty is to know whether one is weighing truly comparable components in each case. Moreover, as every designer of experience knows, there is one good reason for not broadcasting structure weight details—without a full knowledge of the prevailing circumstances at the time of the design it is impossible to say whether a structure is representative of its class or of its designer. Every effort has been made to ensure that the data given are reliable.

Mr. Davies places one in a difficulty. One does not feel called upon to answer his contribution in detail, as it is largely an expression of opinions, without in all cases evidence which appeals as conclusive to support them. But

he again has fallen a victim to what one regards as the aspect ratio plague. His drag coefficient formulæ are for *aspect ratio* 6, which means, for a biplane with equal wings, a span $1/\sqrt{2}$ times that of the monoplane. But nowhere in his contribution is any account taken of this fact in estimating structure weight. One is unable to agree that any satisfactory conclusion can be reached by such reasoning.

PROCEEDINGS

FIFTH MEETING, SECOND HALF, 64TH SESSION

In the Chair: THE PRESIDENT, COLONEL THE MASTER OF SEMPILL

A meeting was held under the auspices of the Royal Aeronautical Society in the lecture theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2., on Monday, March 4th, 1929.

THE PRESIDENT: For over sixty years this Society has listened to lectures on aeronautical matters, but the importance, from an imperial point of view, of the present lecture cannot be over-stressed.

A few weeks ago something that was characteristic of this country occurred. It was this. In the cold and fog of Liverpool Street Station, London, someone arrived home, and there was only a handful of people there, some half-dozen or so, to welcome this person. There were one or two representatives of the Air Ministry, and one or two representatives of this Society, the Society of British Aircraft Constructors, and the Air League of the British Empire. The person they welcomed was our lecturer. If such a thing had occurred in any country other than this, crowds of people would have been at the station and would have lined the route he was to follow, in order to give him an enthusiastic welcome. There may be some who will disagree with this view, but one must differ from them. The country at large must be brought to realise the immense benefits resulting from this wonderful cruise which has been carried out by Group Captain Cave-Browne-Cave and the officers and airmen of the Royal Air Force.

Group Captain Cave-Browne-Cave joined the Royal Navy somewhere about 1903. He served in the Royal Navy for approximately 10 or 12 years before joining the Royal Naval Air Service, and at the commencement of the War he was the Engineer Officer at the Royal Naval Air Service seaplane station at Grain. Later on he was appointed Commanding Officer of the test section at Port Victoria, where various types of machines were designed and constructed. In 1917 he was in command of the seaplane stations at Dunkirk and at Felixstowe respectively, and later he went on to Malta. In April, 1918, he was awarded the Distinguished Service Order for his magnificent service in night bombing operations at Dunkirk. In 1919 he was awarded the Distinguished Flying Cross. For some time he served at the Royal Naval Staff College at Greenwich, and later on was appointed Chief Technical Officer at the School of Technical Training at Halton. For some five years from 1922 he occupied an important position in the Research Department of the Air Ministry, and was subsequently appointed to command the Far East Flight. No better choice could possibly have been made for that command. Those who have the privilege of knowing Group Captain Cave-Browne-Cave are aware that one of his very many good qualities, and one which no doubt weighed very much with the authorities when they made this admirable appointment, is that he is an extraordinarily thorough in everything he does and a very sound technical officer. His meticulous thoroughness manifests itself in all the stages of this remarkable cruise, and undoubtedly it explains in some measure at least why such phenomenal success was achieved.

Among those present to-night who have done great work in other spheres must certainly be mentioned—Lady Bailey. There are also present Squadron Leader Hinkler, and two other officers of the Royal Australian Air Force, who are about to return to Australia by air. There is someone else who has distinguished himself very much in connection with the development of the flying boat; one refers to Squadron Leader Scott, who made such a very fine cruise with the Under-Secretary of State for Air.

THE CRUISE OF THE ROYAL AIR FORCE FAR EAST FLIGHT

BY

GROUP CAPTAIN H. M. CAVE-BROWNE-CAVE, D.S.O., D.F.C., F.R.Ae.S.

I am indebted to the Air Ministry for permission to read this paper to you; this permission does not commit them to agreement with the opinions I have tried to express.

1. Formation and Objects of the Flight

The Royal Air Force Far East Flight formed at Felixstowe in May, 1927, to carry out long cruises in the East with four flying boats of the Southampton type. Some of the principal objects of the cruises were:—

(*a*) To give Service personnel experience in carrying out long cruises with a Flight operating independently of surface vessels and shore bases, and to exercise their initiative and resource under widely varying conditions.

(*b*) To gain technical and operational experience for the development of flying boats.

(*c*) To collect information on seaplane bases, harbours and local conditions affecting aircraft throughout the routes flown; and

(*d*) To show the flag and foster the spirit of mutual co-operation between the Mother Country and the parts of the British Empire visited.

The personnel of the Flight consisted of a Flying Party of four boats' crews of two officers and two airmen each, and a Base Party of three officers and 23 airmen. All the officers in the boats' crews were pilots, and one of these had specialised in aerial navigation. One airman of each boat's crew was a fitter; the other was a W/T operator in two of the boats, a fitter in the third boat, and a carpenter rigger in the fourth boat. The function of the Base Party was to assist the boats' crews during the formation of the Flight at Felixstowe, and during the stays of the Flight at Karachi and Singapore. During the time the Flight was cruising, the Base Party was employed at the new air base which is being built at Singapore, except that one officer and four airmen were sent from Singapore to Melbourne during the stay of the Flight there, in case any considerable repair work might be required. All the flying boats' crews were unchanged throughout the cruises of the Flight. The only changes in the Base Party were the loss of one airman, who died of sleepy sickness in hospital at Singapore, and the addition, at Singapore, of one medical officer, one fitter driver, and 37 Asiatics who were employed as transport drivers, telephone operators, coolies, waiters, sweepers and labourers.

2. Programme and Route

The original programme of the cruise was drawn up by the Air Ministry, and allowed an ample margin for meeting any delays. After the first stage had been flown the experience gained showed that the stays allowed at the end of each stage were unnecessarily long, and they were reduced; the time thus saved was used in increasing the time spent cruising round India, extending the stage from Singapore to Hong Kong and back to include Bangkok, Victoria Point and Penang, and in completing the cruise a month earlier. The programme modified in this way was divided into four stages as follows:—

Stage 1.—Leave Felixstowe on October 14th, 1927, and Plymouth on October 17th, flying thence via Aboukir and Baghdad to Karachi, arriving there November 18th.

Stage 2.—Leave Karachi on December 15th, 1927, and fly round India and Ceylon to Singapore, arriving there by the end of February, 1928.

Stage 3.—Leave Singapore on May 21st, 1928, and fly through the Dutch East Indies to Australia, spend June along the West and South coasts of Australia, July at Melbourne, August along the East and North coasts of Australia, and return through the Dutch East Indies to Singapore, arriving there on September 15th, 1928.

Stage 4.—Leave Singapore on November 1st, 1928, fly through the Philippines to Hong Kong, thence via Saigon, Bangkok and Victoria Point to Singapore, arriving there on December 11th, 1928.

The ports to be visited during each stage were selected to fulfil the objects of the cruise as far as possible, consistent with meeting the wishes of the foreign countries over whose territories the Flight would pass. The route was not the shortest or the easiest to fly, but it was quite suitable. The average length of each flight was 340 nautical miles (equivalent to Land's End to Newcastle direct). The longest flight was 545 nautical miles (equivalent to Land's End to Kirkwall in the Orkneys direct), and our Southamptons could fly this against a 15 kt. wind on the 500 gallons of fuel carried in their top plane tanks.

Before each stage was started the programme of arrival and departure dates for each port in the stage was approved by the Air Ministry, and forwarded to all the authorities concerned. I was authorised to vary this programme, but did so very seldom, as any change might inconvenience the authorities at the ports visited. Every stage was completed to programme. The lists of ports visited, with arrival date, distance, time and average ground speed for each flight, are given in the paragraphs dealing with each stage of the cruise. All alterations of programme and defects causing delays are summarised in one paragraph for convenience in grouping.

The objects of the cruise, and the programme to be followed, show clearly that we were not required to fly the route quickly, or make any records. The cruise was a Service exercise, and time was necessary to attain its objects, to allow corrosion barnacles and other consequences of exposure to develop properly, and to determine the effect on the crews of living in small metal hulls in the tropics. The cruise lasted for 14 months, and the route, as flown, was 24,279 nautical miles, apart from local and special flights, circling towns, picking up formation, etc. The corresponding flying time per aircraft was 351 hours 40 minutes, and the average ground speed 70 kts. (80 m.p.h.). The Flight of four aircraft flew the whole route, a total of 97,116 aircraft nautical miles ($4\frac{1}{2}$ times the circumference of the earth at the equator) with 2,811 engine hours' flying. The Flight spent a night or more in 63 different harbours, isolated bays, rivers, lakes, etc., under widely varying conditions, but always moored out or anchored on the water without cover, except for 81 days in the open on land during the stays at Singapore, and 26 days in a shed at Melbourne. A cruise

such as this is long enough, both in distance flown and in time of exposure, for any defect in the design, construction or maintenance of the equipment used, to be found. As four aircraft were used, a good opinion can be formed as to whether any defect developed is peculiar to one aircraft, engine or crew, or is common to the type or Flight. Further, the personnel of the Flight and the authorities along the route get experience of refuelling, accommodating and generally providing for a Flight instead of for a single aircraft only. Such experience might be of great value in time of war or emergency. Provided a reasonable amount of flying is done, the experience gained from aircraft moored out in parts, seldom or never visited by flying boats in the past, but which may be used constantly by them in the future, is at least as valuable as the experience gained in flight. It is probable that considerations of economy, and maintenance of a force ready to meet emergencies, will often force Service flying boats to spend much of their time on the water instead of in the air, just as they force naval ships to spend much of their time in harbour instead of at sea. In consequence of the above I think that a cruise, such as ours, gives more useful experience for a given expenditure, than a cruise with more flying but less time on the water.

3. Preparations for the Cruise and Equipment Used

The information available in the Directorates of Civil Aviation and Meteorology at the Air Ministry, and the Pilots and Charts published by the Admiralty, helped us to select the ports to be visited, and to realise the conditions we might meet. Parts of the route—Southern India, for example—had not been visited by aircraft, but the majority of it had been flown over, and we had the advantage of the experience gained by the American Round the World Flight, the Marquis de Pinedo, Sir Alan Cobham, Group Captain Goble, the R.A.F. Mediterranean Cruise, and others. As the cruise progressed the naval and harbour authorities, and the observatories of the countries visited, and the offices of the shipping companies, fuel agents, and Thos. Cook & Son, all willingly gave additional information which helped the Flight and added greatly to the interest of the cruise. In planning a cruise it is worth remembering that the information required on wind speed and direction, prevalence of heavy rain, fog, storms, etc., is often conveniently summarised on charts for various districts for each month of the year. For example, for the last stage of the cruise the information required was obtained from the November and December sheets of " Maps showing mean atmospheric pressure, wind direction and force over the China Sea," published under the authority of H.E. the Governor of Hong Kong and printed by Noronha & Co., Hong Kong; additional information is given in the Monthly Pilot Chart of the North Pacific Ocean published by the Hydrographic Office, U.S. Navy.

On formation the Flight were equipped with two Southamptons; one was a standard one with wood hull, and the other was fitted with the experimental metal hull built by Supermarine Aviation Works. These were used for our training and experimental work during our stay in England, and were then returned to general service. For the cruise itself the Flight were equipped with five metal-hulled Supermarine " Southampton " flying boats, fitted with 2 Series VA Napier Lion engines each. Four of these aircraft were used for the cruise, and the fifth was shipped to Singapore as a spare. When the Flight formed these aircraft were being built, but there was time to modify them in detail as we wished during construction. We were not in a position to decide immediately on all the detail modifications we wished made, as we would not apply any alteration or fitting to our cruise machines until it has been tested. This was satisfactory for us, but it was rather difficult for the makers, and they did very well in completing our aircraft in time for us to test them and leave exactly to

the time originally fixed by the Air Ministry, more especially as for most of the period they were very busy on the completion and trials of the aircraft which won the Schneider Cup.

The Southampton type with Lion engines had been standard equipment for some time in the Royal Air Force, and had been used successfully for cruises in home waters and to Aboukir and back. The personnel of the Flight included officers and airmen who had served at the two main R.A.F. flying boat stations, and on these cruises. Consequently we were in an exceptionally good position to decide exactly what modifications were required, and the Air Ministry allowed every one we suggested to be made exactly as we wished it. The aircraft and engines proved to be very well suited for the work they had to do, they were convenient and easy to maintain, and the record of the cruise shows that they were extraordinarily reliable. I think these results are mainly due to the facts I have stated above.

I will not attempt to give details of the alterations; they were carried out by Supermarine, who consequently know all about them, and practically the whole of them are now standard in the Southampton type. The following notes indicate generally what was done.

Aircraft

The standard anodically treated duralumin hull and wing tip floats were used, they were finished with white enamel inside and out, except that the inside of the hull bottom up to the chines was grey. Two scuttles were fitted on each side of the hull below the centre section, the hinges were aft, and the scuttles had side plates which made them very effective wind scoops when open. Proper stowages in the hull and centre section were arranged so that the whole of the equipment, cooking stove, food, water, clothes, spares, charts, emergency rations, medical kit, awnings, cockpit covers, tools, bilge pump, refuelling gear, etc., were stowed, and the hull was clear for the crew except for the rubber dinghy, which was deflated, folded up and stowed on the floor plates under the pilots' seats, and the anchor rope which was coiled down under the front rudder bar position. The drogues and tripping lines were stowed in pockets on the centre section so as to avoid bringing water into the hull.

The size of the two fuel tanks in the top plane was increased to 250 gallons each; they were made of tinned steel painted white; light alloy tanks would have been lighter, but we would not have been able to repair them with our own facilities, and they might corrode internally when not completely full of fuel—throughout the cruise we only refuelled to the amount of fuel we actually required for the work in hand, and had no trouble with any of the tanks. Drains were fitted in the bottom of each tank and at the lowest point of the fuel system, and the water condensed in the tanks was always drawn off immediately before flight. The oil tanks were increased to 18 gallons each to leave an ample air space above the 14 gallons of oil carried for flights with full fuel; these tanks were fitted with a baffle with small holes in it so that only a small quantity of oil was circulated when the oil was cold, and even in cold weather the engine could be run up safely to full power as soon as the water was warm. With these oil tanks no oil coolers were required during the cruise. The maximum oil temperature in flight was 68°C. with a strut temperature of 27°C. Oil coolers with five elements each were fitted for trial between Singapore and Perth; they reduced this oil temperature about 7°C.

The radiator surface was increased to nearly 50 per cent. more than the standard radiators used in home waters; we found that with shutters wide open the maximum water temperature in flight during our cruise was 76°C., so there was a good margin for flying with one engine, or for towing another aircraft on the water.

The drinking and washing water was carried in two portable five-gallon drums and one four-gallon ready-use tank with a tap in the bottom for filling saucepans, etc. These water containers were anodically treated duralumin, and each had a large hand hole closed with a cap, so that they could be thoroughly cleaned.

Light awnings were made to protect the hull forward and aft of the superstructure from the sun when on the water; they could be pulled down to keep the rain out of the hull without having to put the cockpit covers on and spoil the ventilation, and they were so arranged that they did not interfere with work on the moorings.

Gear was made and tested for getting a spare engine on to the centre section with the aircraft moored out, flying it to the aircraft requiring it, and changing engines on the water. An extensible strut was made which enabled wing root struts to be changed with the aircraft moored out. The tail trolley was redesigned so that the whole of the beaching gear could be carried inside the hull and flown to an aircraft requiring it. None of this gear was carried in the aircraft during the cruises; it was sent with the spare engine to the main depot for each stage (Karachi, Singapore, Melbourne and Hong Kong), being moved on from one to another of these as the stages of the cruise were completed.

Care was taken to ensure that every part of the aircraft, except the hull bottom, could be examined, cleaned and maintained with the aircraft moored out; and tear-off inspection patches were fitted on the fabric surfaces as necessary for the examination and adjustment of the internal wires and fittings. Steel fittings, nuts, bolts, etc., were made of stainless steel as far as possible. The streamline wires and struts were zinc-coated and painted. Light alloy parts were anodically treated, where this was applicable, and those outside the hull were painted also. Particular attention was given to preventing water getting into the fabric-covered surfaces where rods, wires and pipes come out, and to drain the inside of these surfaces completely—the drain-hole must be flush with the surface and not stand up above it like an eyelet.

A lavatory was fitted behind a canvas screen in the tail of the hull, discharging direct into the sea behind the rear step. This position is just clear of the water with the boat at rest at the moorings, but comes under water when the boat is pitching or taxying. These lavatories were unsatisfactory and were removed at Melbourne, and a cut-down oil drum with removable seat and lid was substituted. This was satisfactory as nearly all the flying was over the sea and the aircraft were always afloat when crews were living on board.

A portable bilge pump, rather like a garden syringe except that it was fitted with short lengths of suction and discharge hose, was substituted for the fixed bilge pumping arrangements; it was very effective but rather tiring to work inside a hull in the tropics, as it discharges on the upstroke only.

The portable bunks consisted of a frame of duralumin tube with canvas lashed to it. They were slung from the top and side of the hull when in use; when not required they were folded up and stowed either close against the hull side or in the tail of the hull. No boat carried more than two of these bunks, as comfortable sleeping billets on the flying kit on the floor of the hull, in hammocks slung between the engine bearers, or in the inflated rubber dinghy were soon found.

Particular care was taken to prevent any petrol getting into the hull; all fuel tanks, pipes, cocks, refuelling gear, etc., were kept outside the hull, consequently cooking, lighting mooring lamps and sleeping inside the hull were safe from petrol fumes—no smoking or naked lights were allowed from the time the refuelling boat approached until half an hour after it had left and refuelling was completed.

The armament gear was not fitted—it was shipped to Singapore in case of emergencies. The only armament carried was a Service automatic pistol, a Verey's pistol, and a .22 rifle with appropriate ammunition in each boat.

The above appears rather a formidable lot of alterations, but it should be remembered that the Southampton type was originally designed to operate from bases in temperate climates, whereas we were to use it without bases in a wide range of climates including the tropics.

Engines

The engines were standard Napier Lion Series V.A. engines with the gas starting gear, braided cable and magneto screening removed. These engines develop a normal full power of 500 b.h.p. each, and two were fitted in each aircraft.

Equipment

I shall only mention the main items of equipment.

Each boat carried one anchor of the Mark XII.A type developed by M.A.E.E., Felixstowe; it weighed about 58 lbs. The anchor line was 15 to 20 fathoms of 2½in. Manilla rope with a cut splice 7 fathoms from the anchor end to which sandbags could be shackled when additional holding power was required. These sandbags were carried empty and were filled with any suitable material available before use.

Evans jackets were used as flying and flotation jackets. The standard R.A.F. flying topee was used with sponge rubber pads over the ears and anti-glare goggles.

No parachutes were carried, and the thick cushions in the pilots' seats thus made possible were very comfortable, made good lifebuoys, were used as fenders, and in one emergency to buoy the position of the moorings.

The cooking stove was a duplex roarer type, carried in a small aluminium box with a hinged top and front, so that it could be used on the cooking table in normal conditions, on the centre section in hot weather on the water, or on the floor plates out of the draught in flight. The cooking gear, plates, teapot, basins, etc., were aluminium and were anodically treated; they were stored in a cupboard under the cooking table.

The bedding of each man was a sleeping bag—practically a large eiderdown sewn up the side with a removable mackintosh bag as a cover—a sheet sewn into a bag to act as a washable lining to the sleeping bag, a light blanket and a cushion or pillow.

Two of the aircraft carried F.20 5in. × 4in. roll film cameras when the flights were over British territory.

Turn indicators and P.4 and O.3 compasses were used. The refuelling gear was a small aluminium hand pump with gauze suction and discharge filters—its capacity against the normal lift of about 18ft. was about 350 gallons per hour—one 12ft. and two to three 7ft. lengths of flexible metallic refuelling hose, with a light stand pipe for dipping through the small bung holes of some barrels. Later in the cruise we found a small filter, which could be pushed on to the end of the stand pipe and very quickly cleaned, saved much time when the fuel was dirty. The fuel was never filtered through chamois leather, and we never had any trouble with dirty petrol in the aircraft tanks or engines.

Each flying boat carried a rubber dinghy; two different types were tried during the first stage of the cruise, and a triangular dinghy designed and made by the Royal Aircraft Establishment was found the best.

Oil mooring lamps were used as many of our stays were over three days, and the accumulators we carried would only run the boats' lighting for that time

before recharging was necessary. We could only recharge the accumulators in flight or by taking them ashore where there were charging facilities. We never found a satisfactory oil mooring light which was compact and light, but I understand they are being developed.

The personal kit of each crew of four weighed about 180 lbs., and we found that anodically treated aluminium suitcases, designed to fit between the frames of the hull, were lighter for a given capacity and more satisfactory for flying boat work than normal suitcases.

The spares carried by each boat consisted of one inlet and two exhaust valves complete with springs, 24 sparking plugs with washers and clips, a contact breaker for the main and for the starting magneto, an oil filter cap, 6ft. of H.T. cable, 6in. lengths of various sizes of I.R.P.R. tubing, ½ sq. ft. of 22 gauge copper sheet for patching water jackets, a spare drogue, an oil funnel, a sorbo rubber pad which could be forced against the bottom between the frames (also useful as a fender or cushion), two small leak stoppers, spare parts for metal couplings, asbestos and water pump packing and jointing material, gauze for filters, a little fabric and fabric strip with needles and thread, dope white enamel and brushes, a few short lengths of duralumin angle bar, lamp bulbs, W/T valves and aerial weights, eight yards of Unisheath electric cable, carbon brushes for the generator, a spare H.T. battery, an electric torch, grease, tallow, locking wire, copper wire, insulating tape, fibre and emery cloth, a selection of rivets, screws, bolts, nuts, washers, split pins, clips, joints, control wire and thimbles. The tools included the small engine tool kit, oil can, small vice, soldering gear, and a small carborundum stone. Divided between the four boats of the flight were two wood airscrews with bosses (later replaced by two metal airscrew blades when all the Flight used metal airscrews), one streamline wire of each size and length used, two magnetos, one single and one duplex carburettor float, twelve piston and scraper rings, two collets for airscrew hubs, and a few special joints and tools such as the airscrew extractors.

The total weight of each flying boat completely equipped for the cruise, with crew on board, was 14,600 lbs. when carrying the normal 400-gallon fuel load, and 15,400 lbs. when ready for the longest stages with full tanks (500 gallons fuel). The span of the Southampton is 75ft., the length 50ft., the area of the main planes 1,450 sq. ft., and the normal full power 1,000 b.h.p.

The same four aircraft, S.1149 to S.1152, were used throughout the cruise, except that, on the arrival of the Flight at Singapore from Australia, the spare Southampton (S.1127) which had been shipped to Singapore, changed places with S.1149 for experimental purposes, in accordance with Air Ministry orders.

The Flight had a total of 22 Napier Lion engines. Eight of these were used for the first three stages of the cruise, by which time they had completed over 300 hours' flying each; they were then removed for examination and refit, and the next eight engines were fitted. The remaining six engines were not used, but were available as spare engines in case of trouble.

The main supply of stores for the Flight was sent to Singapore and Melbourne; part of the former went via Karachi in case the Flight might need them there. The part of the Melbourne stores not used by the Flight and required by the R.A.A.F. for their Southamptons were sold to them, and the remainder were returned to Singapore for the use of the Flight there. The stores for Hong Kong were sent up from Singapore and the unused ones were returned there.

In addition to the above, a few spares were put down at intermediate ports; for example, for the last stage (4,655 sea miles) spares were put down at Manila and Bangkok; these consisted of an oil filter cap and spring, some Jubilee clips, water pipe connections and parts, a water pump lubricating cup, a contact breaker, some sparking plugs, carburettor parts, linen fabric and strip, control wire, and nuts for exhaust pipe flanges.

The fuel supplies allowed for a possible head wind of 20 kts. on any stage, with a margin of 50 per cent. to cover losses by leakage, evaporation, spilling during refuelling, rejection of dirty petrol, etc. The Flight used much less fuel than this, as the wind on the average was slightly favourable and the losses from the causes named about 5 per cent. The oil was changed about every 20 hours' flying. The oil removed always appeared in good condition, but the period between changes was not extended as many places visited were very isolated and spare engines were far away—for example, for the Australian stage of over 10,000 miles, our spare engines were at Singapore and Melbourne.

Small supplies of paraffin for the cooking stove and mooring lights, and distilled water for accumulators, engines and drinking, were also arranged. The distilled water was perhaps a luxury, but it is not difficult to put it down with the fuel, and we hoped its use would avoid troubles due to furred-up radiators, corroded water jackets, and sickness due to drinking impure water—we had none of these troubles. In a few cases the distilled water was supplied in containers which were dirty or had contained acid, and it had to be rejected. Fortunately at these places good water was obtainable locally.

Arrangements were made for moorings for the four boats to be available at each refuelling base. We asked for a holding power equivalent to 15 cwt. of iron on the bottom. These moorings were generally extemporised from the material available locally.

The personnel of the Flight were fully occupied in preparing for the cruise, receiving instruction in semaphore, morse, cooking, boat work, first aid, swimming, etc., and in learning their special duties. For example, the W/T operators were responsible to the first pilot of their boat for the cooking, rigging repairs and adjustments, cleaning of hull and superstructure, mooring gear and lamps, in addition to their duties with the W/T and electrical gear. As any airmen of a boat's crew might be left in charge of a flying boat at moorings, he had to practice starting up the engines and slipping moorings single-handed, taxying the boat in traffic, etc. All the fitters in the boats' crews were taught simple flying. All the alterations to the aircraft and the equipment had to be tested out. Each crew had to practice working and living together as a crew; maintaining the aircraft and changing engines, etc., on the water without dropping essential parts overboard. All the personnel were kitted up for foreign service, inoculated, vaccinated and sent on a month's leave before the aircraft for the cruise were ready for delivery at the end of September.

On October 13th everything was ready, the boats were launched, tested and moored out at Felixstowe, and the Flight was inspected by senior officers from the Air Ministry and Coastal Area.

On October 14th the Flight left Felixstowe at 09.00, flew to Plymouth, secured to buoys in the Cattewater and refuelled. The conditions during most of the flight were rather unpleasant with rain and mist, but the weather was good at Felixstowe and Plymouth. During the flight the bottom water elbow on the starboard radiator of one aircraft split at the flange. As there was time, a new radiator was obtained from the makers and fitted. Longer rubber connections were bought in Plymouth and fitted between these elbows and the bottom water pipes in all the aircraft, so as to reduce the risk of similar failures during the cruise; this proved quite effective. The Air Ministry had stronger elbows and stays for the bottom water pipe made and sent out to the Flight; these were fitted at Singapore. A small leak was found in the oil tank of one aircraft, where the supporting tube passes through the tank—this was repaired.

The Flight were very fortunate in the preparations for the cruise, everyone concerned had helped us willingly, often at considerable personal inconvenience. We had been able to test out everything we were taking, and all the alterations we wished for had been made.

4. The Cruise

During the cruise the Flight received the greatest kindness, hospitality and help from the authorities and residents wherever we went. I am sorry that time does not allow me to tell you more of this, as it contributed very much to the success and enjoyment of the cruise, and the whole Flight are very grateful for it. The best testimony I can give of the help and kindness we received, is the regularity with which the Flight was able to carry out the cruise, and the fact that all boats' crews finished each stage fit and well and anxious for the next.

At several places which had been visited by aircraft before, the authorities asked me to do what I could to warn pilots intending to make long flights of the importance of keeping the local authorities informed of proposed movements and changes of programme affecting the areas for which they are responsible. Unless this is done the authorities cannot see that everything is ready, and they are given much anxiety. In foreign countries arrivals without previous warning put our representatives in a difficult position. Many of the landing grounds in the East are used for other purposes when not required for flying; they are liable to become unsafe in the rains, are often far from towns and villages, and have no transport available unless this is arranged beforehand. Our Flight were working to a programme, and consequently it was easy to give the authorities ample notice of our movements and wishes; this was always done and was largely responsible for the ease and promptness with which the cruise was made.

It is impracticable to give more than the barest outline of the cruise in this lecture. Full reports on each stage of the cruise, with all available information on weather conditions, facilities at ports visited, behaviour of equipment, loads carried, take-off times, etc., have been rendered to the Air Ministry, and they have allowed extracts from the diary of the cruise to be published. As time is so limited I will give a short description of the routine followed, details of all alterations of programme or defects causing delays, tables giving details of the flights made on each stage with a brief description of the conditions found, and a few notes on the experience gained.

As the result of the experience gained in the first few flights the following procedure was followed for the remainder of the cruise, except for small alterations made occasionally to meet the wishes of local authorities. The crew of each flying boat was two officers and two airmen. A guard of at least one officer and four airmen (one in each flying boat) was always on duty in the flying boats, except at Aboukir and Hinaidi where the local Royal Air Force units arranged the guard, and during the time the boats were on shore at Singapore and Melbourne. All officers and airmen dined and slept in the flying boats the night before a flight, but apart from this it was usual to allow the officers and airmen off duty to live ashore if suitable accommodation was available. It was usual for each flight to start at daylight, all crews having a good breakfast on board before the start, and for all flying boats to refuel immediately they had moored at their destination. As soon as the wishes of the local authorities had been ascertained a cable was sent to the authorities at the next port stating the date and time we would arrive (they already had our programme and knew the quantities of fuel, etc., to be sent off to us as soon as we moored, and the routine we would follow). Another cable was sent to the Air Ministry stating the movements of the Flight—in general the one word "programme" was sent, meaning that the Flight had arrived and would leave to programme. In nearly every case the authorities did exactly what we asked, and refuelling was completed in less than two hours, and often in less than one hour after arrival. The officers and airmen of the Flight, except the C.O.

who went ashore temporarily to make the necessary arrangements, send the cables, etc., remained in the flying boats until refuelling and routine work was done; they had their lunch either during the flight or in the flying boats before going ashore. Motor boats were only allowed alongside the aircraft in very special circumstances. The flying boats always manœuvred on the water, picked up moorings, etc., under their own power and without assistance. During each flight the two officers in each boat flew in turn, changing over every hour to the duties of navigator and observer. The fitter took control of the aircraft from the rear pilot's seat whilst the officers changed places in the front pilot's seat.

Except for a few places where the conditions were cramped or difficult the Flight took-off, flew and landed in formation. Whilst cruising the Flight was in a V formation, with two on one quarter and one on the other quarter of the leading machine, which carried the navigator; the interval between aircraft was normally about half a mile. The actual landing or take-off was made in the V formation used for cruising except that it was closer to suit the conditions. For manœuvring after taking-off, and before landing, circling towns, etc., the Flight closed up into a diamond formation with intervals of about two spans, and the rear machine just below the slipstream of the leading machine. Very close formation was never used as the formation looked better when fairly open and the pilot's attention was always more or less occupied in recognising the shallows, buoys and other obstructions in the harbour, and in identifying the moorings. The normal height of the flights over the sea was about 1,000 ft., over the land it was generally higher, for example, for crossing the toe of Italy it was about 6,000ft. The Flight normally cruised at about 1,920 r.p.m., which gave, on the average, about 69 kts. by air speed indicator, with a fuel consumption just under 50 gallons per hour.

At some of the ports visited additional flights were made at the request of the local authorities. For example, at Hinaidi, King Ali flew over Baghdad; at Karachi G.O.C. Sind Brigade, the Commanding Officers of the Sherwood Foresters, the 10th Baluch Regiment, Royal Artillery Manora, and other officers and prominent civilians flew over the town. At Karachi and Bombay the Flight formed part of the escort for the Amir of Afghanistan. None of these flights is included in the statistics of the cruise given in this lecture. For a few flights of the cruise itself officers were carried on duty. For example, A.O.C. India, was carried from Karachi to Bombay, and Colonel Schelmerdine from Calcutta to Rangoon.

5. Alterations of Programme and Defects Causing Delays

(Complete cruise—four aircraft 24,379 nautical miles each)

(*a*) *Fuel Not Available*

Whilst at Brindisi the Flight was informed that no fuel was available at Suda Bay, the next port of call. Consequently the Flight went to Athens instead of Suda Bay on the way to Aboukir, and arrived at the latter place to programme. The arrangements made at very short notice by the R.A.F. members of the British Naval Mission to Greece, and the fuel agents at Athens, for the reception and refuelling of the Flight at Athens were very good, and their action was typical of the way in which everything possible was done to help the Flight throughout the cruise.

(*b*) *Weather*

(1) During the flight from Alexandretta to Hinaidi, head winds much stronger than those foretold by the weather forecast were met. Baghdad informed us by W/T that the wind there was 37 to 51 m.p.h. at 1,000 ft. As

it was doubtful if the fuel left would be sufficient to complete the flight under these conditions, and the last part of the route was over the desert from Ramadi to Hinaidi with no suitable landing for flying boats, the Flight landed on the Euphrates at Ramadi and anchored there for the night, refuelling from the stock of petrol normally kept there by R.A.F., Iraq. The rubber dinghies carried by the Flight were used for this, as no boats were available locally. The sandbanks in the river shift each season and we had no chart showing the channels. The water was too sandy for the shallow patches to be seen. A fair idea of the depths was obtained by sounding over the bow with the boat hook, and the Flight anchored clear of the channel, down which several native craft drifted during the night. Each aircraft grounded lightly whilst taxying to find a safe place to anchor, and before taking-off in the morning, but no damage was done. The Flight flew on to Hinaidi in the morning. The experience was valuable to the Flight and the only regretable part of the incident was that anxiety was given to R.A.F., Baghdad, as the signal informing them that the Flight had landed safely and required no assistance could not be got through till late at night, owing to the storm stopping land line and W/T communication till then.

(2) Due to the partial failure of the monsoon in Southern India, there was too little depth of water for the Flight to land in Chambarambakam Tank (near Madras) as arranged, and the Flight landed at Pulicut Lake instead.

(3) At Chilka Lake a heavy morning mist delayed the start of the Flight one hour.

(4) At Broome, Carnarvon and Israelite Bay (all on the West or South coasts of Australia) the Flight proceeded to the next port one day ahead of programme, due to the exposed position of the moorings and the probability of bad weather. In each case the extra day was spent at the next port, so as to return to the programme.

(5) At Hong Kong a warning was received, from the Director of the Royal Observatory, that the centre of a typhoon would probably pass over Tourane Bay on the day the Flight was due to be there. The flight to Tourane was delayed three days by the movements of this typhoon. These three days were regained by shortening the stays at three subsequent ports by one day each. Such delays affect shipping as well as aircraft. H.M.S. Hermes was due to leave Hong Kong for Borneo on the day the Flight was due to leave for Tourane, she delayed her departure to avoid the typhoon and left Hong Kong after the Flight.

(c) *Defects*

(1) On October 21st, 1927, half an hour before Cape Corse (North Corsica) was reached, one aircraft reported oil leaking from the starboard engine. She was ordered to " land " in sheltered water and rectify the defect. She did so in a small bay on the east side of Cape Corse. The defect was a split nipple where the oil pressure gauge pipe is connected to the engine; this was rectified by blanking off the connection (a new nipple was fitted later). As she hoisted the signal that she would " take-off " again within 15 minutes and required no help, the rest of the Flight circled her till she rejoined, and the whole Flight then proceeded. The total delay was about 15 minutes.

(2) On February 13th, 1928, whilst circling in formation after " taking-off " at Mergui, the connecting rod between the centre and starboard rudder of one aircraft was seen to be disconnected from the centre rudder. This had no noticeable effect on the control of the aircraft, which flew in formation with full load without the pilot knowing anything was wrong. The defect occurred as the aircraft was " taking-off " and it could not be seen by the crew in flight as

it was hidden from them by the tail plane. The Flight landed and the defect, which was due to a broken eyebolt in the centre rudder, was temporarily repaired. The Flight then continued the cruise. The total delay was two hours. The design of this part has since been altered.

(3) On May 23rd, 1928, one aircraft " landed " between Sumatra and Java, due to one of the accumulators, which was being charged, catching fire and filling the hull with smoke and fumes which streamed out past the pilot. The senior boat " landed " beside her to find out why the " landing " had been made and no signal sent. The fire was put out without assistance, the accumulator and its box and wiring being the only parts damaged. Both aircraft then " took off " and rejoined the remainder of the Flight which was circling them, and the Flight then proceeded. The total delay was about 30 minutes. This landing was not essential and would not have been made if the landing conditions had been dangerous. The accumulators were so installed that they could do no damage, except to themselves, if they did catch fire, and the fire was put out without difficulty with one of the two small fire extinguishers carried. Under the circumstances at the time the pilot was justified in landing immediately to investigate and rectify the defect. Tests with the accumulators and installation were made later, and showed that such a fire was very difficult to produce. The only alterations made were a slight revision in the orders for the maintenance and inspection of the electrical installations and a modification to the attachment fittings of the accumulator box, which made its removal easier.

On November 17th, 1928, a sparking plug in the port engine of one aircraft slacked back about an hour after the Flight had left Salomergue to cross the China Sea to Hong Kong. This defect made the engine run unevenly. As the weather and sea conditions were very bad at the time—in fact the worst experienced during the cruise—the Flight returned to Salomergue to rectify the defect. The wind at sea was very strong (30 to 35 kts.), and there was no possibility of refuelling or shelter during the flight to Hong Kong (460 nautical miles); consequently the Flight had to refuel at Salomergue, and as this was unexpected it could not be completed in time for the Flight to reach Hong Kong that day. The authorities concerned were informed that the flight to Hong Kong was postponed a day, and the Flight left accordingly at dawn next morning, and reached Hong Kong without further incident. The total delay was one day. This defect was exceptional, and the Flight orders which warned fitters that over-tightening sparking plugs would lead to water leaks round the bosses, were not altered.

(5) On November 29th, 1928, the front half of the metal airscrew boss on the port engine of one aircraft was found to be cracked on arrival at Tourane. The nearest spare was at Singapore, and it would have taken some weeks to get it to Tourane. Temporary repairs were made that night, which enabled this aircraft to proceed with the rest of the Flight to Saigon at dawn next day in accordance with the programme. These temporary repairs were unsatisfactory, and the resultant vibration started a leak in the radiator which necessitated a " landing " for temporary repairs during the flight to Saigon. This aircraft remained at Saigon when the rest of the Flight went on to Bangkok to programme. On arrival at Bangkok one of the aircraft returned to Saigon with an airscrew from another aircraft of the Flight. This airscrew was fitted to the aircraft at Saigon and these two aircraft flew to Bangkok, thus re-forming the complete Flight. In the meantime the spare airscrew boss had been sent from Singapore to Bangkok in accordance with a signal sent by the Flight. This boss was fitted with the blades from the defective boss, and all four aircraft continued the cruise from Bangkok without this incident delaying the programme. Although the part that failed had flown 367 hours without trouble, and the similar parts in the other aircraft of the Flight gave no trouble at all,

it is understood that this defect is not an isolated case and that these parts have since been redesigned to prevent it. The incident was of value to the Flight, as, to save time and gain experience, the aircraft flying the airscrew from Bangkok to Saigon, and the two aircraft returning from Saigon to Bangkok, started their flights with insufficient time to complete them in daylight; they landed, anchored and spent the night en route in an isolated bay which appeared suitable, and they had no trouble at all.

(6) *Delays in Starting.*—At Sourabaya, on the outward journey, a leak of sea water through the lavatory lid joint of one aircraft, whilst taxying down the long channel there, made it necessary to pump out the bilge before taking-off; this delayed the Flight about ten minutes. After 225 hours' running one engine of one aircraft became rather difficult to start; this delayed the start three times, each less than ten minutes; and at St. Kilda, after the completion of the stage to Melbourne, this engine took nearly half an hour to start. The valves of this engine were ground in during the stay at Melbourne, and this cured the trouble. At Point Cooke and at Port Darwin one suction oil filter needed priming after the engine started. This took about five minutes each time.

(d) Requests by Local Authorities

At the request of H.E. the Governor of the Straits Settlements and High Commissioner of the Federated Malay States the flight from Port Swettenham to Singapore was postponed from February 27th to February 28th, when he and three members of his staff were flown down in the aircraft of the Flight to Singapore.

Summarised as above the delays, etc., appear very much more than they did to us, and it should be realised that they were spread out over more than a year, and any defect in one of the four aircraft affected the whole Flight. As regards the delays in starting, eight 500 h.p. engines had to start at the first attempt by hand-turning gear, generally at dawn after a night moored out; they almost invariably did so.

6. 1st Stage: Felixstowe—Karachi

Date of arrival. 1927.		Place.	Distance from previous port Nautical Miles.	Flying Time. H.	M.	Average Ground Speed Kts.
		Felixstowe	—	–	–	—
October	14th	Plymouth	276	4	5	68
,,	17th	Hourtin	380	5	5	75
,,	19th	Berre	310	4	25	70
,,	21st	Naples	440	7	–	66
,,	25th	Brindisi	230	3	40	63
,,	28th	Athens	340	4	55	69
,,	29th	Aboukir	500	6	35	76
November	3rd	Alexandretta ...	442	6	30	68
,,	5th	Ramadi	418	8	30	49
,,	6th	Hinaidi	60	1	10	51
,,	10th	Basra	260	4	–	65
,,	12th	Bushire	190	2	45	69
,,	14th	Henjam	348	4	40	74
,,	16th	Gwadar	380	5	45	66
,,	18th	Karachi	260	3	35	72
		Totals	4,834	72	40	

Average Ground Speed 66.5 kts.

The weather conditions during this stage were generally favourable. The Flight left England in drizzle and the wind soon freshened to about 25 kts. with rain and low clouds, but the weather cleared up at Ushant. During the stay at Hourtin there was heavy rain on one afternoon. The flight to Berre was made in good weather, except that Bordeaux was under fog with the spires standing out and looking very fine above it, but a safe forced landing in the river there under these conditions would have been impossible. From Berre to Aboukir the weather was good, except for one day of the stay at Naples, when there was heavy rain and a southerly wind of 25 to 30 kts. Some heavy rain and thunderstorms were passed through between Aboukir and Cyprus. The conditions during the flight from Alexandretta to Ramadi were mostly bad. There was heavy rain in the early morning, which stopped just before daybreak when the Flight took off in a moderate south-west wind. The low clouds in the pass over the mountains, and the down currents due to the strong easterly wind on the east side of the mountains, made crossing the mountains difficult. The conditions were then good, except for the strong head wind, until the Euphrates was reached. The remainder of this flight was in alternate rain and dust with visibility down to about 200 yards for considerable periods. Although all this part of the flight was made below 400ft. and the air speed was increased to 75 and sometimes to 80 kts., the ground speed was often below 45 and the average for the flight was 49 kts.—the lowest during the cruise. A thunderstorm started shortly before the Flight landed and heavy rain fell frequently during the night. The flight on to Hinaidi next day was in fine weather, but there was a heavy rain and thunderstorm that night. The weather conditions from Hinaidi to Karachi were good. The Flight just missed the hot weather in Iraq and the Persian Gulf. The strut temperature in flight varied from 46 to 82°F., and the hull temperatures on the water seldom exceeded 80°F.

The conditions and facilities on the route are fairly well known now, and will be very well known soon when the Imperial Airways service to Karachi is running.

H.M. Ships Enterprise and Triad were met at Bushire and Henjam, and entertained the Flight very kindly. The Flight was put in quarantine at Bushire, due to an outbreak of cholera in Iraq, and the personnel were not allowed to land. This did not prevent the Persian Authorities and British residents being shown over the flying boats.

This stage included two rather long overland flights. In each case there were rivers for a considerable part of the way, and although, as far as we could judge, a landing in most of the Euphrates above Ramadi would have been dangerous, I do not think such flights in flying boats involve any greater risks than flights of similar length in landplanes over the open sea or bad country, or in flying boats over rough seas. With good equipment properly maintained and used within its capacity, the risk of forced landing is very small; it should be practically negligible with multi-engined machines capable of climbing with one or more engines dead. If a forced landing has to be made in really bad country, rocky mountains, swamps, forests, etc., I think the passengers and crew would have a much better chance in a flying boat such as the Southampton than they would have in a landplane, as the all-metal hull is strong and can be crumpled up a great deal before the occupants are jambed, there is no fuel in the hull, and the bow is long enough to make turning over improbable.

The landing and mooring sites at Hinaidi were very suitable for us owing to the care taken by the Royal Air Force there in preparing for the Flight, but larger aircraft might have trouble due to the shallows. Aircraft moored in the river at Basra are very likely to be damaged by drifting native craft unless special precautions are taken to protect them; these precautions were taken by the Royal Air Force unit there. The arrangements for the

moorings and refuelling at the Persian ports were made by A.O.C., Iraq, and were admirable.

Karachi

The flying boats lay at their moorings in the river opposite the shipping wharves. There was much traffic, but—thanks to the harbour police patrol—nothing ran into the aircraft. The Base Party arrived in Karachi on November 20th and relieved the crews of the flying boats of their guard duties in the boats. The Flying and Base Parties were accommodated at Manora Barracks, except that the officers of the Flying Party lived in a hotel in Karachi, and one officer of the Base Party at the Royal Air Force Depot some twelve miles away.

The aircraft and engines were thoroughly inspected and found in very good condition; no components required renewal and the adjustments made were very minor. The only defect of any importance was the growth of barnacles and weed on the hull bottoms. The bottoms appeared to be clean when inspected in flight just before landing at Karachi, but after a fortnight in the harbour there they were so foul that each boat was beached for a day just before the Flight left, and the bottom was scrubbed down and given a coat of enamel.

The Flight left England with two boats using metal airscrews and two using wood airscrews. We found nothing to choose between the two types in performance or cooling, but as the wood airscrews had given trouble sufficiently severe to necessitate the spares carried being fitted, whereas the metal type had given no trouble at all, we gave up the wood airscrews and used metal airscrews on all the aircraft for the rest of the cruise.

7. 2ND STAGE: KARACHI, ROUND INDIA AND CEYLON TO SINGAPORE.

Date of arrival. 1927.	Place.	Distance from previous port Nautical Miles.	Flying Time. H.	M.	Average Ground Speed Kts.
	Karachi	—	–	–	—
December 15th	Bombay	475	7	–	68
,, 27th	Mangalore	395	5	45	68
,, 29th	Cochin	195	3	15	60
,, 31st	Colombo	315	4	30	69
1928.					
January 12th	Trincomali	290	4	45	60
,, 19th	Pulicat Lake ...	325	5	30	60
,, 20th	Cocanada	300	5	–	60
,, 23rd	Chilka Lake ...	225	3	45	60
,, 27th	Calcutta	290	4	10	70
February 2nd	Akyab	315	4	30	70
,, 6th	Rangoon	320	4	10	76
,, 13th	Mergui	310	4	15	73
,, 16th	Penang	475	6	25	74
,, 23rd	Port Swettenham ...	160	2	20	68
,, 28th	Singapore	210	2	30	84
	Totals	4,600	67	50	

Average Ground Speed 68 kts.

The aircraft and engines were again very satisfactory. The only troubles of any importance during the cruise, apart from those already recorded in paragraph 5, were:—

(1) Heavy deposits of barnacles occurred on the bottoms of all the hulls during the twelve days' stay at Colombo. These increased the " take-off " time at 14,700 lbs., under the conditions there, from 30 to 50 secs. The hull bottoms were cleaned down in shallow water at the next port (Trincomali) and the " take-off " returned to normal.

(2) The joint washer under the nut and steel washer of the T bolt of the water supply elbow to the rear of the outer block cylinder head of the starboard engine of one aircraft failed during the flight to Pulicat Lake. Towards the end of the flight the water loss from this leak made the closing of the starboard throttle desirable, and the last twenty minutes of this flight were flown with this throttle shut. As the fuel load was light, the aircraft was able to keep in the formation. A new washer was cut and fitted during the stay of the Flight on Pulicat Lake. The engine was undamaged and gave no further trouble. The design of this part has now been modified.

This stage was flown in the north-east monsoon period. The weather was fine with light winds, mostly land and sea breezes, down the West coast of India. On the West coast of Ceylon the N.E. monsoon was not yet properly established and there was rain and sometimes thunder, mostly in the evenings. South of Ceylon a very heavy rain squall was met, in which flying was dangerous, but the worst of this could have been avoided. At this time of year, late December and early January, depressions to the east of Ceylon move north-west meeting the coast near Madras; in one quadrant they cancel the north-east monsoon and light south-westerly winds may occur; in another quadrant they combine with the monsoon and the north-easterly winds may increase to about 30 kts. We met north-easterly winds up the East coasts of Ceylon and India; their speed was 15 to 20 kts. at the southern end of the coast, gradually decreasing as we flew north, with occasional morning mists from Madras to Calcutta. Down the West coasts of Burma, Siam and Malaya the winds were generally light and northerly. Morning mists were frequent at Akyab and Rangoon. The weather was fine till we reached Penang, where we landed in light rain which soon developed into a heavy rain and thunderstorm with a strong wind which stopped the refuelling. It passed off in about an hour. There was light rain for short periods during the rest of the stay at Penang, and low clouds with occasional rain squalls down to Singapore, where the Flight arrived just before another heavy thunder and rainstorm which lasted about half an hour. From Penang to Singapore the winds were northerly, light at first and increasing to about 20 kts. at times near Singapore.

Most of the West coast of India was very suitable for seaplanes during the north-east monsoon, and there were many stretches of water just inland from the coast which appeared to be very suitable for emergency landings in bad weather, if the water is deep enough. Round Ceylon and up the East coast of India to a little north of Madras, the open sea was too rough for the present types of flying boats to " take off " safely, and suitable landing places were much less common. The remainder of the route was very suitable for seaplanes.

Singapore

The Base Party arrived at Singapore before the Flight. The site for the seaplane base is at Seletar, on the Johore Strait, on the opposite side of the island, and about fourteen miles away from Singapore. A few of the airmen were accommodated in temporary huts at Seletar as a guard, the remainder were in military barracks near Singapore. The officers of the Base Party lived in a house at Seletar, and the officers of the Flying Party had to live in Singapore. There were temporary huts used as an office and stores and a shelter for the spare Southampton hull with centre section in place. The slipway was sufficiently built to get the aircraft ashore near high tide, and there was an area of concrete on which they could stand.

When the Flight arrived, the aircraft were brought ashore for thorough examination and repainting. This examination showed the aircraft to be in very good condition; the only defect of any consequence was corrosion of some of the rivet points below the waterline; these were renewed. The exposed steel parts, other than those made of stainless steel, were corroding a little. For example, the zinc coating and paint had come off parts of the wing root struts and streamline wires; these parts were cleaned and repainted. Some of the external cables such as the mooring gear and part of the aileron control above the hull were rusty, and were renewed. Some of the split pins were rusting and staining the enamel near them; they were renewed. The rigging needed practically no adjustment. Some of the nuts on the tops of the inner vertical interplane struts and on the eyebolts of the inter-rudder connecting rods required tightening slightly, due presumably to slight timber shrinkage. The fabric was a little slack at night and in rain, but otherwise taut. It was sound except for a little chafing by the front spar, and an 8in. wide fabric strip was doped over this. The top surfaces were given a coat of V.84, which reduced the slackening in rain and at night. A few minor jobs were done, such as easing the hinges of scuttles and lockers, and fitting " wriggles " to prevent rain running down the side of the hull getting in through the scuttles when they were open for ventilation. The hulls were thoroughly washed down and repainted externally with white enamel, except that three of the bottoms were finished with a coat of a special V.84 with added gums sent out by the Air Ministry to see if it was a better protection against barnacles and corrosion of rivet points than the white enamel.

The average running time of the engines was about 156 hours, and they were all running well, except that two exhaust valves were blowing slightly. As time was available and the next stage was a long one, all cylinder blocks were removed and the valves ground in. The deposit of carbon on the inlet valve stems was rather more than normal. A total of twelve exhaust valves, one gas ring, and one scraper ring, were fitted between the eight engines. In two engines the outer races of the rear roller bearings of the airscrew shaft had been spinning and were two to three thousandths slack; new races five thousandths oversize were shrunk in without dismantling the engine. In two of the sixteen main magnetos the base plates of the contact breaker groups were slightly slack; this was put right. Apart from the above, all parts seen were in excellent condition, and the same engines were used throughout the next stage of the cruise.

8. 3rd Stage: Singapore, via Dutch East Indies to Australia, Round Australia, Staying a Month at Melbourne, and Back to Singapore

The aircraft and engines were again very satisfactory. Details of the only delays during this stage have been given in paragraph 5. They were due to an an accumulator catching fire whilst being charged, a lavatory lid leaking during taxying, occasional slight trouble in starting an engine, and two cases of an oil filter requiring priming when the engine started. These delays totalled less than two hours. The only other parts giving trouble were:—

(1) One inter-rudder connecting rod broke and was repaired at Broome. The attachments for this part have since been re-designed.

(2) In three of the aircraft the port forward outer inter-plane W strut started to vibrate at about the cruising speed, small alterations of rigging did not stop this, but in each case it was stopped by removing a short length of the fairing near the centre of this strut where it passes close to the engine mounting.

(3) One magneto was changed due to the bolt securing the condenser breaking. This part has since been modified.

(4) On two occasions an engine started to run unevenly and drop revs. to 1,800 for a few minutes and then recovered. Some bits of dirt, apparently corroded aluminium, were found in the float chamber.

(5) Several of the air intakes started to crack near the flange which connects them to the carburettor. This part was slightly strengthened and the trouble stopped.

(6) Three small water leaks occurred in the engines. One where the waterjacket is welded to the aft sparking plug boss of No. 1 cylinder, and two where the water pipe is welded into the waterjacket of the duplex induction pipe. These were made good without difficulty.

(7) A large quantity of sea water came into the hull of one aircraft through the lavatory whilst taxying to moorings after refuelling at Batavia on the outward journey. This was cleared by the bilge pump, and all the lavatories were removed at Melbourne.

(8) At Port Darwin a heavily laden motor boat ran down wind and tide into the bows of one aircraft which was moored up, knocking a hole in the bow. This was repaired by the flying boat's crew.

Date of arrival. 1928.		Place.	Distance from previous port Nautical Miles.	Flying Time. H.	M.	Average Ground Speed Kts.
		Singapore	—	–	–	—
May	21st	Klabat Bay	215	3	20	63
,,	23rd	Batavia	320	5	45	60
,,	25th	Sourabaya	370	6	–	62
,,	28th	Bima	375	5	40	65
,,	30th	Koepang	310	5	20	60
June	1st	Broome	470	6	55	68
,,	3rd	Port Headland ...	260	3	30	74
,,	6th	Carnarvon	495	7	55	62
,,	7th	Perth	460	6	–	77
,,	15th	Albany	270	3	50	70
,,	19th	Israelite Bay ...	330	4	30	73
,,	20th	Murat Bay	515	7	10	72
,,	22nd	Adelaide	350	5	15	66
,,	29th	Melbourne	475	6	20	75
July	30th	Paynesville	200	2	40	75
August	1st	Sydney	350	4	45	75
,,	11th	Brisbane	430	6	10	72
,,	18th	Gladstone	260	4	30	58
,,	19th	Bowen	280	4	10	67
,,	24th	Cooktown	340	4	35	74
,,	28th	Thursday I	360	4	15	91
,,	29th	Melville Bay	350	4	20	86
,,	30th	Port Darwin ...	370	4	20	85
September	1st	Koepang	470	6	15	75
,,	3rd	Bima	310	4	15	71
,,	4th	Sourabaya	375	4	55	76
,,	9th	Batavia	370	4	45	78
,,	14th	Klabat Bay	275	3	30	79
,,	15th	Singapore	235	3	–	78
		Totals	10,190	144	5	

Average Ground Speed 71 kts.

The Flight was brought ashore at Point Cork for the month's stay at Melbourne, and for most of that time they were under cover in a seaplane shed. One officer and four airmen of the base party had been sent from Singapore to Melbourne in case any considerable refit might be necessary, but the aircraft and engines were found to be in very good condition. The corrosion of the rivet points and other parts had been much less than during the Indian stage and there were few barnacles on the bottom. This improvement was probably due to the cooler water. The special V.84 was found to be a much better protection for the bottom than the white enamel, but there was nothing to choose between the two finishes in keeping barnacles and weed off. A few rivet points had corroded sufficiently for renewal, these were all in the bottom finished with white enamel. All the lavatories were removed. All the superstructures were in good condition and only minor adjustments were necessary. The fairings were removed from the tail unit struts and inter-rudder connecting rods, as these parts are subject to heavy spray when taxying and corrosion had started under the fairings. Additional wires were fitted from the tops of the outer interplane struts to the bolts on the lower plane attaching the side bracing wires of the wing tip floats, this greatly relieved the stresses in the main spars when a wing tip float is struck sideways by a sea. One pair of side bracking wires to a wing tip float was replaced, due to corrosion. A few of the pins in the engine mounting torque tube struts were slack in their holes, the holes were reamered out and larger pins fitted. One metal airscrew blade was changed as it appeared to be rather more flexible than the others. A few other minor replacements and adjustments were made.

The outward and return flights through the Dutch East Indies were in the south-east monsoon period and the weather was good, except between Singapore and Klabat Bay, where heavy rain squalls were met for short periods on both the outward and return flights. The winds were generally between east and south-east, but varied considerably in speed and direction as the Flight was often under the lee of high ground; between the islands the wind was generally blowing up the channels at about 15 kts. On the flight from Batavia to Sourabaya a storm was seen well to the north of the track of the Flight. Two water spouts were seen in Sumba Strait. The sea was calm for both the outward and return flights between Koepang and Australia, during the former there was a little rain early in the flight and the wind was easterly and under 10 kts. till Australia was reached, when it was S.W. 8 kts. During the return flight it was fine all the time, with south-easterly winds under 10 kts. The flight round Australia was made in June, July and August, their winter, and the Flight was very fortunate in avoiding weather sufficiently bad to delay them from North-West Cape round the south of Australia and up to Brisbane. The west coast from Broome to Perth, and the south coast from Albany across the great Australian Bight to Murat Bay have long stretches with no shelter for flying boats. The rest of the route is very favourable for them. Although there was a good deal of rain and low cloud on most of the flights from Broome to Melbourne and some nasty squalls during the flight from Murat Bay to Adelaide the weather generally was better, and was never worse, than is frequently met in the English Channel.

At Broome two flying boats parted, and at Cooktown one flying boat dragged the moorings, but the guard left on board prevented any damage being done. At Koepang one of the flying boats dragged its mooring over the edge of a ledge into deep water, and proceeded to drift with the moorings hung from her bow. The engines were started, but the heavy mooring could not be taxied up on to the ledge again. Fortunately the standard mooring gear with slider had been modified by the Flight and it was possible to unshackle the mooring pendant completely from the bow of the flying boat. This was done, a light line

and cushion being used to buoy the position of the moorings. The flying boat then taxied into shallow water and anchored. A boat was obtained from the Dutch ss. Gemma and the moorings were weighed and relaid correctly.

Singapore.—On arrival back at Singapore the aircraft were brought ashore and again secured in the open at Seletar. In accordance with Air Ministry orders one of the aircraft which had carried out the cruise had to be left at Singapore for a detailed examination involving cutting parts out of the hull. As all the four aircraft were in the same condition, S.1149, the first one delivered, was detailed for this and her crew was transferred to the spare Southampton S.1127, which joined up with the other three for the last stage of the cruise. The aircraft generally were in very good condition, the rigging was true and only minor internal or external adjustments were necessary. The deposit of barnacles on the bottom was slight. The corrosion of the rivet points was going on slowly and about 400 were renewed. The corrosion of the steel struts under the fairing was now sufficient for a few of the engine bearer struts to be renewed. A little water had been getting into the space between the leading edge and front spar of the lower centre section, through the inspection doors and round the lubricator nipples, radiator shutter wires, etc., causing deterioration of the fittings inside and the three-ply sides, but this had not gone far enough to be serious. The mooring strops, drogue wires, petrol cock controls and the aileron control wires which pass through the top of the hull were renewed due to corrosion. In one aircraft water had got into the plane where the air speed indicator tubes come out, had run down the underside of a compression rib and corroded a light alloy plate under the horn carrying the inner aileron hinge; the leak was stopped and the horn attachment strengthened. In another aircraft the drain hole in one centre section locker had been blocked and a little water had collected, deteriorating the three-ply. On all four aircraft the packing blocks at the tops of the vertical struts of the wing tip floats were renewed, due to crushing by the loads from the wing tip floats. The fabric surfaces were still satisfactory, a few strips were doped on where the fabric had been chafing. The top surfaces of the main plane and ailerons, the under surface of the top centre section, and the tail unit were given one coat of V.84. The internal structure of the planes, etc., was in very good condition, the bolts through the tail plane spars and those holding the fins required a little tightening, due to wood shrinkage. The hulls were repainted with white enamel and the bottoms finished with the special V.84. One metal airscrew blade was changed as tapping on the surface produced a sound as if one of the formers or distance pieces inside was loose.

The engines of the three original aircraft continuing the cruise were all removed for overhaul, as they had completed 300 hours' flying and the next stage would take about 70 hours more. The spare engines were fitted.

9. 4TH STAGE: SINGAPORE, VIA PHILIPPINES TO HONG KONG AND BACK TO SINGAPORE VIA SAIGON, BANGKOK AND VICTORIA POINT

The aircraft and engines were again very satisfactory. Details of the defects causing delay have been given in paragraph 5, they were a loose sparking plug which caused the Flight to put back to Salomague, and a cracked airscrew boss which delayed one aircraft in reaching Bangkok. The only other troubles were:—

(1) At Hong Kong a motor boat ran into the wing tip of one aircraft at her moorings, doing a considerable amount of local damage. This was repaired.

(2) Whilst taking-off at Tourane a piece of drift wood in the wash broke four former ribs and tore a hole in the leading edge of the tail plane

of one aircraft. This did not delay her, and the damage was repaired when she landed.

(3) At Tachin three aircraft dragged their moorings. The moorings were relaid and no damage was done.

(4) One magneto was changed, due to wear in the plain distributor bearings. In the present type of magneto, ball bearings have been substituted for the plain bearings.

Date of arrival. 1928.	Place.	Distance from previous port Nautical Miles.	Flying Time. H.	M.	Average Ground Speed Kts.
	Singapore	—	–	–	—
November 1st	Kuching	410	6	–	68
,, 5th	Labuan	380	5	55	66
,, 7th	Princessa	350	5	20	66
,, 9th	Manila	350	5	35	63
,, 16th	Salomague	260	3	55	66
,, 18th	Hong Kong	460	7	15	63
,, 29th	Tourane	520	7	5	74
,, 30th	C. St. Jacques, Saigon	450	6	15	72
December 2nd	Tachin, Bangkok ...	545	7	–	78
,, 7th	Victoria Point ...	250	2	55	86
,, 8th	Penang	310	4	35	68
,, 11th	Singapore	370	5	15	71
	Totals	4,655	67	5	

Average Ground Speed 69.4 kts.

This stage was flown in November and December, which is the early part of the N.E. monsoon and the wet season along the east coasts of Malaya and Annam and the north coast of Borneo, but the dry season for the rest of the route. The Flight met a good deal of rain at first, but the storms were local and all the heavy ones were avoided by small alterations of course. There were some heavy thunder and rain storms whilst we were at Kuching—about one a day—and one at Labuan. This season is comparatively free from typhoons, but we knew from the records of past years that one would probably form to the east of Luzon and pass over to near the Amman coast, re-curving northwards. A severe typhoon did this whilst the Flight was at Hong Kong, and although it delayed the Flight three days, as already stated, it did not come close enough to give us bad weather. The Flight could move much faster than the typhoon and I think we could have avoided it whatever course it had taken, as we were in a very good position to know its probable movements. The worst weather we experienced was in the east of the China Sea between Salomague and Hong Kong. We knew it was practically certain that we should find a N.N.E. wind of 25 to 30 kts. with low clouds, occasional rain and a very rough sea, and it was so. We tried flying above the clouds which ended at about 3,000 ft., but, although the conditions were much better there, we had no means of finding our drift, and consequently had to come down under the clouds again. Owing to the cracking of one airscrew boss, already reported, the route between Saigon and Bangkok was flown three times, and we found that by flying from Saigon below 2,000 ft. and returning above 2,000 ft. a favourable wind could be obtained for each of the overland crossings. The navigator found this on the first flight by noting that the cloud shadows on the ground were travelling in the reverse direction to the wind in which we were flying. It was confirmed by one aircraft of the Flight flying up into the reversed wind, and by

the subsequent crossings. On the flight up from Puerto Princessa to Manila the weather was bad on the east coast of Palawan and we avoided it and the strength of the head wind by crossing over to the west coast, where the conditions under the lee of mountains were good but rather bumpy.

The route flown is generally suitable for seaplanes. There is of course practically no shelter on the crossings between Singapore and Borneo, and from Salomague to Hong Kong; the latter is nearly always rough, at this period, for the eastern half of the flight. The chart alone is not a reliable guide to the suitability, for seaplanes, of the rivers in Borneo, as there is often much heavy drift wood and some have dangerous "bores."

On arrival back at Singapore the aircraft of the Flight were all flying very well and giving no trouble, and I have no doubt they could have flown back to England if that had been in accordance with Air Ministry policy. They are being refitted by the Base and Flying Parties at Singapore, and by now several of them are again in commission there. The deposits of barnacles were less than on the Indian cruise, but more than on the Australian cruise.

During all the stages of the cruise the roltine maintenance work was carried out by the boats crews. On an average one control wire required renewal in each aircraft about every 60 hours flying. The equipment and instruments were very satisfactory, except that a revolution indicator failed occasionally, due, I think, to there being no means of lubricating its mechanism without stripping it; the pink liquid in the strut thermometers lost its colour after about four months exposure, and the aneroid we carried instead of a barometer, was reading about .3in. low at the end of the stages, although it was tested and re-set before each.

10. General Notes

(*a*) *Hulls*

In many harbours in the East serious deposits of barnacles take place on the hull bottoms if flying boats are moored out more than a few days. The warmer and dirtier the water the quicker barnacles seem to grow. Once they get a good hold they are very difficult to remove and generally bring the protection paint away with them. We did not find any protective coating which prevented their growth, but they grew much quicker on the black recognition marks, than on white enamel. The best general protective for the hull bottoms we used was V.84 varnish with gums added to make it stick better. The only serious corrosion took place on the rivet points, and some alternative to duralumin rivets is required to prevent these parts needing renewal long before the rest of the structure. We tried Monel metal in a few places, it did not corrode or cause corrosion, but was rather too hard. The work of renewing rivets is much easier when the internal fittings, the hull-lockers, etc., are attached by bolts and easily removed. There was practically no corrosion on the surface of the anodically treated duralumin plates, except a little in places where sea water could lie stagnant—under stiffening plates and angles and in the actual joints. The hulls had no double bottoms and they did not leak at all after about the first fortnight, when the few tiny leaks in the joints had been found and stopped. A hull ran fairly hard on a sand bank occasionally, but this never damaged it. We found green canvas attacked duralumin when wet with sea water; it attacked the frame of the tail trolleys and was removed. We used white duck canvas for our awnings and covers, this was quite satisfactory, but some of the Flight had experience of balloon fabric covers, and considered them neater and better. The type of beaching gear used on the Southampton in which the hull bottom is clear for work without jacking up, which can be flown to the aircraft requiring it, and which cannot damage the hull bottom, is very much better than a trolley. If we had used wood hulls I think we should have had trouble with borer worms, as in about three months at Singapore they ate through the bottom of a dinghy

and through a painted wood frame of 3in. spruce, which was holding some metal samples in the water.

(b) *Wood Shrinkage*

The wood frame of the superstructure shrunk very little and practically no internal adjustments were necessary. I think this was due to the care with which the wood parts had been sealed with varnish, and the more constant humidity of the air close to the sea compared with conditions inland. A few of the external nuts on bolts passing through wood members required tightening occasionally, I think larger and stiffer packing blocks would have prevented this.

Deterioration

I understand it is difficult and costly to make parts of stainless material, but I think it will save trouble and be cheaper in the end to use stainless material wherever possible in seaplanes which have to be exposed for long periods. Zinc coating, painting, etc., do very well for a short time, but they will not resist exposure to warm sea water for long. The best protective coating we used was V.84 with added gum for painting on, and lanoline for greasing. It is essential to prevent sea water getting inside the fabric covered surfaces, and particular attention must be given to maintaing watertightness of inspection doors and where wires, rods, tubes, etc., come out through the surfaces. If the top of the hull by the centre section is not watertight, rain will drip in and make living inside unpleasant; the places where rain may get in are similar to those in the fabric surfaces. The stowages for tools and spares must keep the water out. The fairings of struts must not allow water to get in and collect. Metals which attack each other when in contact with sea water must not be used in contact. Control cables working over pulleys should be avoided if possible, where they must be used the short length that wears should be connected to the rest of the cable by shackles, so that only short lengths have to be renewed, and it should be possible to fit these short lengths after the eye at each end has been spliced. The edges of former ribs, spars, etc., where fabric may chafe should be rounded and protected with tape. All these points are well known, but I doubt whether it is realised how vitally important they are in flying boats, particularly if they are to be used in the tropics. Our Southamptons were particularly well protected against deterioration, and we were all surprised at the way they stood up to the very severe test.

Rubber Dinghies

The triangular rubber dinghy carried by each flying boat weighed just under 50 lbs., complete with pump, oars and repair outfit, and was invaluable. It was used for communication work, and on three occasions for refuelling, and was available for life saving; it could be used for maintenance work under the planes and tail plane without fear of damaging the aircraft. It is a good bath and a comfortable bed, and can be used on the bottom plane to give access to parts which are otherwise difficult to reach.

Living Conditions and Health of Crew

Two officers and two airmen can live and sleep in a Southampton in reasonable comfort for short periods; but as the conditions are cramped, the food monotonous and mostly tinned, and fresh water very scarce, it is undesirable for the same men to be in the boats for more than a few days on end. In hot weather the temperature in the hull is no more than in the cabins of ships under the same conditions. In cold weather the boats are very cold even with the cooking stove burning and the ventilation reduced to a minimum with the cockpit covers. Continuous rain or a moderately rough sea make conditions on board very uncomfortable. The crew generally slept well in the boats, but

occasionally the slapping of the water on the hull bottom and the jerking of the boat at its moorings make sleep difficult. During the cruise the crew slept on board a good deal. For example, on the last stage, which lasted 41 days, the average number of nights slept in the flying boats was 17 by each officer and 27 by each airman. The general health of the crews was extraordinarily good considering the climatic conditions. The full crews were available for every flight except two. In each of these cases one officer had Dengue fever and could have come on with the Flight, but as it was possible for him to travel by other means and rejoin the Flight at the next port, and as the local doctors recommended this course, it was followed. The only accident of any consequence was that an airman upset a frying pan of boiling fat whilst cooking at Hong Kong. This scalded his right leg and foot rather badly and he was on light duty in the flying boat for some time. He recovered completely, thanks largely to the treatment he received from the medical authorities at the ports visited.

Navigation and Weather

For the open sea stages the track made good was found by taking stern bearings on some mark on the sea, either the mark from a wave crest or a stain on the surface produced by dropping a small packet of aluminium powder. Very good land falls were made in each case. The weather reports obtained over most of the route gave little or no information about the winds at height. Such information would be of value in finding the best height to fly. For long stages with no shelter, warning of strong adverse winds is important. Information on the height to which the monsoon winds hold would be very useful; our experience on the Saigon-Bangkok flights (already mentioned) shows that in some cases there is a reverse wind at quite a low height. Information is also required on the height to which typhoons extend, as it may be possible to avoid them by flying above them. We did not meet any really bad weather, none in fact worse than is often met round the British Isles; but there was bad weather about, and if we had been flying at night and unable to see it, we might frequently have run into it instead of avoiding it. We did not fly in the south-west monsoon on the coast of Burma, or in the north-east monsoon on the East coast of Malaya, or in the typhoon season in the Philippines, or in the cyclone season on the Australian coast, consequently we did not experience really bad weather conditions, but we could have often got better conditions by flying above the clouds if we could have navigated with reasonable accuracy without sight of sea or land. I doubt whether directional W/T will solve this problem, as it may be dangerous to use your W/T above a bad tropical storm when you need it most.

Take-off

The longest " take-off " time was 60 secs., but the average with full load in the tropics was under 40 secs. When the spare boat was tested after shipping to Singapore, eight months in the packing cases there, erected and in the open and standing there for one month, with five hours' flying, its " take-off " was found to be the same, with the same load and conditions, as the other boats which had been in the open a year with 300 hours' flying.

Risk of Damage

The times the aircraft were most likely to be damaged were when they were moored in crowded rivers with fast currents, much traffic, and drifting native craft—Basra and Rangoon are examples. The next most serious risk was when motor-boats tried to come alongside the aircraft, or when steam or motor-boats crowded with sightseers came close to the aircraft without realising that the latter swing quickly when moored in a gusty wind. The local authorities at

the ports visited were most helpful in assisting the Flight to avoid these risks. Some of the ports visited were very open—Broome and Israelite Bay for example —and in a few cases the moorings were not secure. Unless moorings have been laid by the harbour authorities, or fishermen, or someone with a good knowledge of seamanship, they should always be tested before the crews leave the flying boats to the guard.

Help by Ships and Air Stations

The experience of the cruise shows that a Flight of flying boats can carry out long cruises, under a wide variety of conditions, working independently of ships and shore stations, without any serious delays. We received assistance from ships—for example, H.M.S. Enterprise met us at Bushire and sent in a boat to help us refuel, and entertained the officers and airmen off duty very kindly. Another example is the Philippines, where the U.S. Navy sent tenders to ensure we had every help. We also visited several air bases and were very kindly entertained and helped. These ships and air bases, and the arrangements they made, were a great assistance to the Flight and greatly increased the interest and enjoyment of the cruise, but the Flight visited so many places where there were no air bases or ships to help us, that I think there can be no doubt that a Flight could operate independently.

Refitting in the Open

Practically all the refitting of the aircraft was done in the open, and this was useful experience, but we learnt that, although it can be done in emergency, it is wasteful and inefficient to work without shelter and facilities. Work on, and in, flying boats standing in the open on shore is extremely exhausting under tropical conditions, far more so than when the boats are afloat. In a place like Singapore, where for considerable periods there is generally one or more heavy rain squalls each day, the work is much delayed. Such operations as painting, doping or opening up a plane for examination often have to be put off because of the risk of rain before the work is completed, and when the conditions appear favourable and the work is started, it is often spoilt by a sudden squall wasting the labour and material that has been expended, and leaving the aircraft worse than it was at first. Further, the jury gear used when some part of the aircraft structure is removed for repair must be made strong enough to resist squalls, and handling large aerofoils in gusts is dangerous.

Operation

The refuelling bases for the Flight were selected to give the best shelter available for " landing," refuelling, mooring and " taking off." No attempt was made to refuel the boats or " take off " with a heavy load in the open sea, and I do not think any existing flying boat, or any one likely to be produced in the near future, will be suitable for such work unless the conditions are very favourable. Our flying boats were a very convenient size; they were large enough to live in and to carry all we required, and yet were small enough to handle easily and to operate from rivers, shallow lakes, etc. Boats of greater draught or with a longer " take-off " would not have been able to use several of the places that were suitable for us. We had, of course, to " take off " sometimes under rather adverse conditions, and the boats did this very well.

Conclusion

I have not had time in this paper to express adequately the gratitude which the Flight feel for the kindness, courtesy and help which they received wherever they went, for the escorts which were sent out to meet them, or for the receptions and entertainments which were given for them. One of these escorts was

a cruise in itself, as the Royal Australian Air Force sent the Amphibian Widgeon II. (Wing-Commander Wackett and Flying Officer Owen) all the way to Broome to meet us on arrival in Australia and escort us to Melbourne.

I also feel rather guilty for saying so much about the defects which troubled us very little, and so little about the good qualities of the aircraft, engines and other equipment which proved so reliable and satisfactory. My reason for writing this paper as I have done is that I hope the experiences of the Flight which I have tried to describe to you may help the development of flying boats. I am sure the makers of the aircraft and engines we used are producing others even better than we had. The officers and airmen of the Flying and Base Parties worked and lived for the success of the Flight with the greatest loyalty. The Base Party often had to work under very difficult conditions, but their work was always completed to time, and the severe test of the next stage of the cruise never found any defect in it. I had complete confidence in every member of the Flying Party, and they showed repeatedly that they were ready and competent to deal with any emergency. Throughout the whole cruise there were no defaulters, no avoidable sickness, and no complaints. Under such conditions the work of the Commanding Officer was easy, and the success achieved was due to the work of the Unit as a whole and not to any individual.

NOTE.—The composition of the V.84 referred to is:—

Nitro Cellulose Syrup	...	260 lbs.
Butyl or Amyl Acetate	...	20 gallons.
Alcohol	...	15 gallons.
Benzol	...	15 gallons.
Acetone	...	16 gallons.
Castor Oil ...	...	25 lbs.
Aluminium Powder	...	100 lbs.

Where necessary Kauri Gum was added to make it stick better.

DISCUSSION

THE PRESIDENT: The lecture just delivered is twice the length of those read to this Society normally, and one feels sure everyone was very glad indeed to listen to such a lecture from Group Captain Cave-Browne-Cave on a subject of such importance. He has been carrying on the work that was done centuries ago by Captain Cook, who was one of the first British navigators to reach Australia, and one may recall the fact that when Captain Cook returned to this country after his great voyage of discovery to Australia he was immediately promoted. The Society, in paying a tribute to Group Captain Cave-Browne-Cave, would like to include also the names of Mr. Mitchell and those associated with him in the design of the machines, Captain Wilkinson and those associated with him in the design of the engines, and also Dr. Watts, who was responsible for the design of the metal airscrews.

This lecture does not contain perhaps quite so much food for discussion as for thought on our part. One wants to learn the many lessons that Group Captain Cave-Browne-Cave has learned and has summarised in his paper, and to benefit from those lessons. Many of the lessons to be learned from the cruise are not so much stated as implied in the lecture. The importance and value of this achievement extends far beyond the confines of the British Empire, and the lessons it teaches will be taken to heart in various other countries. The achievement indicates the wonderful development of our flying boats, engines and equipment generally.

Air Vice-Marshal Sir SEFTON BRANCKER (Director of Civil Aviation): The air voyage which Group Captain Cave-Browne-Cave has lectured on is really

a magnificent performance. The President had asked him (the speaker) to draw deductions from the civil aviation point of view, and there are three important lessons which he would mention. In the first place he was very much impressed by the close analogy between operations of this sort and the operations in the old seafaring profession. The actual flying was fairly easy; the really difficult work was the work on the water. Group Captain Cave-Browne-Cave was a sailor himself, and he thought a good many of those with him were sailors also. He believed that to some extent it was their experience as sailors which helped them to achieve such a wonderful success under all sorts of unexpected and difficult circumstances. The second outstanding consideration is the enormous value of flying boats from the civil aviation point of view. Group Captain Cave-Browne-Cave has described in great detail all the trouble experienced. When one considers it closely one will appreciate that although these flying boats were cruising for over a year all over the world there was extraordinarily little that went wrong. In the whole list of the troubles he has mentioned there was not a single serious item from the point of view of delay or from the point of view of expense. There was absolute reliability and regularity, faultless piloting and apparently faultless maintenance, and if one considers this cruise as a commercial proposition one will conclude that it must have been very economical and very cheap. The third conclusion one can draw from the description of this cruise is the satisfactory one that British pilots and mechanics, and British designers of aircraft and engines, are absolutely unequalled in the world. Given this wonderful material, no matter how far behind this country may be in development to-day, it is bound to come out on top in the end. He was absolutely convinced that no other country can beat Great Britain if it really puts its back into it and developed flying boats as they should be developed. He would like to express the deep gratitude of British civil aviation to Group Captain Cave-Browne-Cave and his officers and crews for the really wonderful demonstration they have given of what can be done and what will be done regularly in the future.

The Rt. Hon. Lord Thomson (late Secretary of State for Air): He had listened to a characteristically modest and matter-of-fact description of what was in point of fact a very remarkable cruise, and one which was most instructive and useful to us all. The Royal Air Force was steadily extending its activities, increasing its knowledge of Empire air bases, and it was also proving its practical value as an adjunct to Imperial defence. Soon it will be much more than a mere adjunct. One can only hope that this cruise will prove to be the first of many others which will serve to knit up the Empire and will show the people of our commonwealth of nations what the British Royal Air Force is.

Engineer Vice-Admiral R. W. Skelton (*contributed*): He believed Group Captain Cave-Browne-Cave and possibly some of his crews were experienced in watermanship and boatmanship, and it seems to him a most important point that the personnel of such expeditions should be just as skilful and experienced in these respects as in airmanship.

He noticed that a somewhat large repair party was sent out,—no doubt advisedly, on the first experiment, but one visualises these craft in the future doing such a cruise entirely on their own resources, and he presumed it had been ascertained from this cruise as to how far it would be possible to do without special repair parties in the future.

No doubt, also, the cost per aircraft per mile and per day of this cruise has been ascertained, and, although he imagined this must have been heavy, a great reduction should be available in the future.

It seemed to him most desirable to extend the time beyond 300 hours when the engine has to be completely stripped down.

Mr. R. J. MITCHELL (*contributed*): The primary reason for the great success of the flight has been the excellent organisation both before and throughout the flight. During preparations every little detail in connection with the flying boats was gone into thoroughly, and nothing was left to chance. Throughout the whole period of about 14 months, during which 97,116 machine nautical miles were flown, one bit of faulty organisation or careless operation might have upset the programme completely. When this is realised it indicates very forcibly what great credit is due to the personnel of the flight.

The vast amount of knowledge and experience gained throughout the cruise has already been of inestimable value in the design and development of the flying boat, and will continue to be so for a very long time. In his reports and lecture Group Captain Cave-Browne-Cave has covered his subject so thoroughly and gone into such detail that it will take a considerable time to digest completely all the information. This also makes it rather difficult to find anything on which to comment or ask questions. There are one or two points, however, which he would like to raise.

(a) *Corrosion of Rivets in Hull.*

He did not recollect any mention that the rivets used in these hulls were in the annealed condition. This was in accordance with standard practice at the time these hulls were constructed. It has since been found that annealed rivets are particularly bad from a corrosion point of view, and that rivets put in in a normalised condition are very greatly superior, when operating around this country. He would like to ask if the replacement rivets used on the cruise were in the annealed or normalised condition, and if the latter, if any marked improvement was experienced in resistance to corrosion.

(b) *Flying at Moorings.*

A certain amount of trouble has been experienced due to flying boats flying at their moorings in a gale. He would like to ask if any precautions were found necessary throughout the cruise, and if so what is considered the most efficient method of overcoming this difficulty.

(c) *Materials of Construction.*

Although the aluminium alloys and ordinary steels with protective coverings used in the construction of these flying boats have stood up remarkably well, he would imagine that they necessitate a large amount of inspection and maintenance. He considered that the rapid development in stainless steel now taking place would bring about a very important advance in flying boat development if they can be used exclusively for construction. He would like to hear how much importance Group Captain Cave-Browne-Cave attaches to this matter.

(d) *General Size of Flying Boats for Empire Flights.*

He was particularly interested in the statements during the lecture that the "Southampton" flying boats were of such a size that they could be operated from small inland waterways and harbours, when it would have been impossible to operate from the open sea owing to its roughness, even with very much larger machines. This has a very important bearing upon the great problem of the size of the flying boat of the future, and he would like to ask if the impression he obtained was correct that Group Captain Cave-Browne-Cave considered a flying boat a little larger than a "Southampton" would prove to be the most efficient size, and that there is not very much to be gained by going into very much larger sizes.

Mr. W. L. Cowley (*contributed*): Group Captain Cave-Browne-Cave has demonstrated to the world the great future that lies before the flying boat. When it is remembered that the cruise was made over coast lines as yet unknown to flying and that landing and mooring places were frequently picked out from charts, the military value of the flying boat is evident. The remarkable reliability and performance of the machines must give the civil side every hope for the future, and one believes the cruise will go a long way to bringing nearer the day when a Far East Air Transport Service is an accomplished fact.

One point in the lecturer's paper gave rise to a slight doubt, and that was concerning the comfort when flying for prolonged periods in the tropics. The lecturer admitted that it is not desirable for the crew to remain aboard more than two or three nights in succession. He would like to know whether Group Captain Cave-Browne-Cave considers that this discomfort would act disadvantageously to passenger transport.

It would be interesting if the lecturer gave some comparative figures showing what he would regard as a reasonable time table for a passenger aircraft service over the route followed and for other forms of transport.

In such a cruise as the one described by the lecturer many duties must fall upon the shoulders of the crews, and he wondered whether a log was kept of all instrument readings. It is by these means that valuable data can be obtained, which will go far to solving many technical and scientific problems. One problem in particular that he had in mind was the question of the effect of tropical conditions upon the performance of aircraft. Some years ago, while he was engaged upon the work of the Air Transport Sub-Committee of the Aeronautical Research Committee, he was brought into contact with this problem, and at the time the view generally held was that the high temperatures in the tropics cause a falling off of top speed and rate of climb, also an increase in the take-off runs of aircraft. The tables given by the lecturer do not indicate any effects of this nature, but it is extremely difficult to discuss the problem without reliable measurements of atmospheric conditions and performance, such as altitude and temperature on the one hand and indicated air speed and engine speed on the other. In the present case there were four machines, and these should furnish fairly reliable average results, and moreover there was one very important fact to be considered, namely, that the same aircraft and engines were used under extreme conditions of temperature.

Reply to Written Contributions

I agree with Engineer Vice Admiral Skelton that the personnel employed in flying boats must be experienced in watermanship and boatmanship. The knowledge required in these respects is rather similar to that required in small cruising yachts. There were eight officers and eight airmen in the flying party; three of these had served in the Royal Navy prior to the formation of the R.A.F., the remainder had obtained the necessary experience in seamanship whilst serving in aircraft in the R.N.A.S. and R.A.F. The strength of the Base Party—three officers and twenty-three airmen—was found very suitable for the work they had to do. A large part of this work was the opening up of the R.A.F. Base at Singapore—drawing stores and making storage facilities, getting the motor boats, transport, spare Southampton, etc., to the Base, erecting, testing and maintaining them. The cruise lasted over a year, and I think flying boats have not yet reached a stage where their flying crews alone can maintain them properly for this period without shelter. The most arduous part of the work was the removal of the rivets in the hull bottoms. Several of the new types of flying boats are being built with stainless steel

bottoms rivetted together with stainless steel rivets, which should overcome this trouble. Much labour was spent in cleaning down and repainting the hulls in the open. With stainless steel this painting will not be required, and the hulls should be much easier to keep clean, as the same trouble will not be necessary to avoid damaging the paint and other protective coatings. I can give no figures for the cost per aircraft per mile or per day on this cruise. The crews and aircraft belonged to the R.A.F., and I think their employment on this cruise was little more costly than their normal employment in home waters. The aircraft were new at the start of the cruise, and, apart from the one returned to England for experimental reasons as reported in the paper, they are all still in use at Singapore. The gross fuel consumption was about 1.6 miles per gallon for each boat. I agree that it is desirable to develop engines so that it is economical to run them more than 300 hours before requiring stripping and overhaul, but I think the advantages to be gained are not sufficient to justify an increase in the weight per horse power. Even in slow aircraft, 300 hours' flying represents a flying distance equal to the circumference of the world at the equator; the overhaul is not costly if it is done in time, and the aircraft need not be laid up whilst it is done, as spare engines can be used.

With reference to the points raised by Mr. Mitchell. Annealed rivets were used in all the hulls, and the replacement rivets were also used in the annealed condition, as we had no heat treatment gear with us with which to normalise the rivets immediately before me. I am glad to hear that normalised rivets stand up better under home conditions than those we had, but to bring the life of the rivets up to that of the remainder of the hull will, I think, make it essential to use a material which will not corrode in sea water. We had no trouble due to flying boats flying at their moorings, as they were never moored in a position when the wind was strong enough for this to happen. The mooring bridle we used was arranged to hold the nose down in a strong wind, and when we expected squalls the elevator and tail incidence controls were set and secured to make the aircraft nose heavy. I think planks on edge, or two bamboos, one above the other, laying along the top of the bottom plane and secured to the bottom of the interplane struts, would greatly reduce the risk of aircraft flying at their moorings. Lines from the mooring buoy to the airscrew bones would also tend to keep the aircraft's nose and angle of incidence down. I agree with Mr. Mitchell that the use of stainless steel and other materials which resist deterioration by sea water without depending on protective coatings is most important for flying boats. The saving in maintenance work and the longer life of the structure justifies the use of such materials, even if they are much more costly. I think there is no one best size for flying boats, and that the most suitable size will depend on the duty the boat has to do. The Southampton was found a very suitable size for this cruise, which included visits to several places where the water is shallow, the "take-off" and "landing" runs short and the facilities for refuelling or repairs very limited. If the boats had been much larger we would have been forced to use other landing places, and in some cases these would have been much more exposed; further, we should have required anchors, which are too heavy to "man handle," if we were to have the same safety, and this involves winches and hawse pipes. The moorings we should have required would often have been too heavy to lay with the facilities available locally. The crew would have had to be larger, as one fitter should not, I think, have to carry out all the work on aero engines totalling much more than 1,000 b.h.p. I am doubtful whether really large flying boats will be able to use the same type of beaching gear as the Southampton, or fly the whole of the gear required for beaching and hull repairs to a sister boat requiring it. For these and similar reasons I think we were able to carry out this particular cruise with greater ease and regularity with the Southamptons than we could have done

with much larger boats. For passenger and mail services running regularly between large ports with organised facilities for aircraft, I think the best size of flying boat will generally be much larger than the Southampton. I think it is reasonable to expect large flying boats to be able to operate under worse sea conditions than small flying boats can, and in this connection ability to "take off" or "land" along a big sea, even if this is side to a strong wind, is very desirable. This seems to require a rounded hull bottom to avoid large rolling moments due to drift, a very strong system for lateral stability on the water, and good lateral and rudder control at low forward speeds. These same characteristics would be very useful also for "getting off" head to wind, where a boat may be thrown into the air and drop a wing before flying speed is reached; for landing in a river or narrow channel with the wind across, where the lateral resistance of a sharp V hull bottom may make the boat swing dangerously, and for mooring out or taxying in a bad sea, where the stresses coming on the wing top floats and lower wings are very severe.

With reference to the points raised by Mr. Cowley. The Southamptons were found to be very comfortable for flying in the tropics, even up to the full range of their tanks, as the pilots can relieve each other as convenient, and the crew can move about, cook and eat their meals quite well; in fact, the only discomfort in flight was the noise, and all crews soon got used to this. My reasons for thinking it undesirable for the same men to live in the boats for more than a few days on end were that the living conditions were rather cramped, the food monotonous and mostly tinned, and the fresh water supply small. I do not think these considerations would affect the passengers, except after a forced landing, as under normal conditions they would generally go ashore for a large part of the time the aircraft is in port. I have never organised passenger services, and consequently have not the necessary experience to suggest time tables for such services over the routes we followed. The readings of the instruments were logged every half hour in flight, with an estimate of the surface wind and the state of the sea. Records were also kept of the conditions when on the water, and for each "take-off." This information was summarised in the report sent to the Air Ministry at the end of each stage. I am afraid it is not a very accurate guide to the effect of tropical conditions on performance, as the aircraft were operating in formation with engines throttled down. It was a long time since the instruments were calibrated, and the total weights of the aircraft were estimated from the known weight when they left Felixstowe.

In conclusion, on behalf of the Flight and myself, I wish to thank the Society very much for all the kind things they have said about the cruise, and the interest they have taken in it.

PROCEEDINGS

SIXTH MEETING, SECOND HALF, 64TH SESSION

In the Chair: THE PRESIDENT, COLONEL THE MASTER OF SEMPILL

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Monday, March 18th, 1929.

The PRESIDENT: The Society welcomes Signor Isacco on the first occasion —and it was to be hoped not the last occasion—that he would address the Society in connection with his machine. Signor Isacco asked to apologise that he was not able to show his film and slides, and added that when the machine now being built at Cowes was flying, he hoped at another lecture to show some slides and films. The general history of the work Signor Isacco was engaged upon was more or less known. It was curious perhaps that the other machine of a somewhat similar character that had been described previously before the Society came from Spain, and Signor Isacco, who was in one time working in Barcelona as an electrical engineer, became associated with Senor Pescara, and gave some attention to the development of the helicopter of the Pescara type. As a result of the work he saw the limitations of the Pescara helicopter, and then conceived the idea of the machine he was to describe that evening. Signor Isacco came over to this country and became associated with a member of the Council of the Society—Major Kennedy—who, with certain friends, helped him to get this machine before the competent authorities at the Air Ministry, who, in their turn, were instrumental in placing an order for the machine now being completed at the works of Messrs. Sanders at Cowes. In calling upon Signor Isacco to read his paper, the President asked the meeting to give him the heartiest of welcomes and to wish him success in the extremely important work he was engaged upon.

THE HELICOGYRE

BY

V. ISACCO

RÉSUMÉ

1. Preamble.

2. Very brief analysis of some types of machines built and experimented with up to the present time.

(*a*) Helicopters (without auxiliary sustaining surfaces)—
  (1) Helicopters with four sustaining propellers turning two by two in opposite directions.
  (2) Helicopters with two sustaining propellers turning in opposite directions.
(*b*) Aeroplane—helicopters (with fixed auxiliary sustaining surfaces).
(*c*) Helicopters with a single sustaining propeller.

3. Aerodynamic analysis of the single sustaining propeller in translation.

4. Helicogyres—
   (1) Articulation of the wings in all directions.
   (2) Variation of the incidence of the wings.
   (3) Horizontal translation.
   (4) Stability of helicogyres.
   (5) Position of the engines on the wings.
5. Comparison of helicogyres with aeroplanes—
   (1) Standstill at a fixed point.
   (2) Horizontal translation.
   (3) Safety of flight.
   (4) Safety in landing.
   (5) Fatigue of the parts.
   (6) Commercial qualities of helicogyres.
6. Helicogyre flight.
7. First practical results already obtained with helicogyres.

I. Preamble

It is a great honour to me to have been invited by the Council of the Royal Aeronautical Society to submit before such a critical audience as this one the result of my studies and work in the very complicated problem of vertical flight.

Possessing but a very imperfect knowledge of English, I must beg of you to be very indulgent with me and to excuse all my shortcomings in the language. I will try to be as explicit as possible.

The problem of vertical flight has puzzled inventors long before the advent of the aeroplane. I shall not go into the history of all the experiments carried out since the beginning, as that would carry me away too far from my subject. My sole purpose in this lecture is to show how, after twelve years spent exclusively in research work in vertical flight, I came to conceive the idea of the helicogyre and the helicogyre flight.

Several inventors and men of renown in their respective spheres have already told you of the results of their studies and research on this problem.

I will make a very rapid analysis of the investigations of the more important amongst them who have worked on different lines, because this will help me to show you clearly the exact causes that have led me towards the solution of vertical flight under an entirely different formula.

II. An Analysis of Some of the Types of Machines Built and Experimented With up to the Present Time

Leaving aside certain machines of quite a special type, we can classify the machines built up to the present time in the following manner:—

(*a*) Pure helicopters (that is to say, without fixed auxiliary sustaining surfaces) sub-divided into
   (1) Helicopters with four sustaining propellers, turning two by two in opposite directions.
   (2) Helicopters with two sustaining propellers turning in opposite directions, in separate axles or in a single one.

(*b*) Aeroplane helicopters (with fixed auxiliary sustaining surfaces).

(*c*) Helicopters, with a single sustaining propeller.

I will make a short survey of these different types of helicopters.

(*l*) *Helicopters with Four Sustaining Propellers*

Helicopters with four sustaining propellers on separate axles, turning two by two in opposite directions, have been experimented with in different countries (Breguet, De Bothezat, Oemichen, etc.).

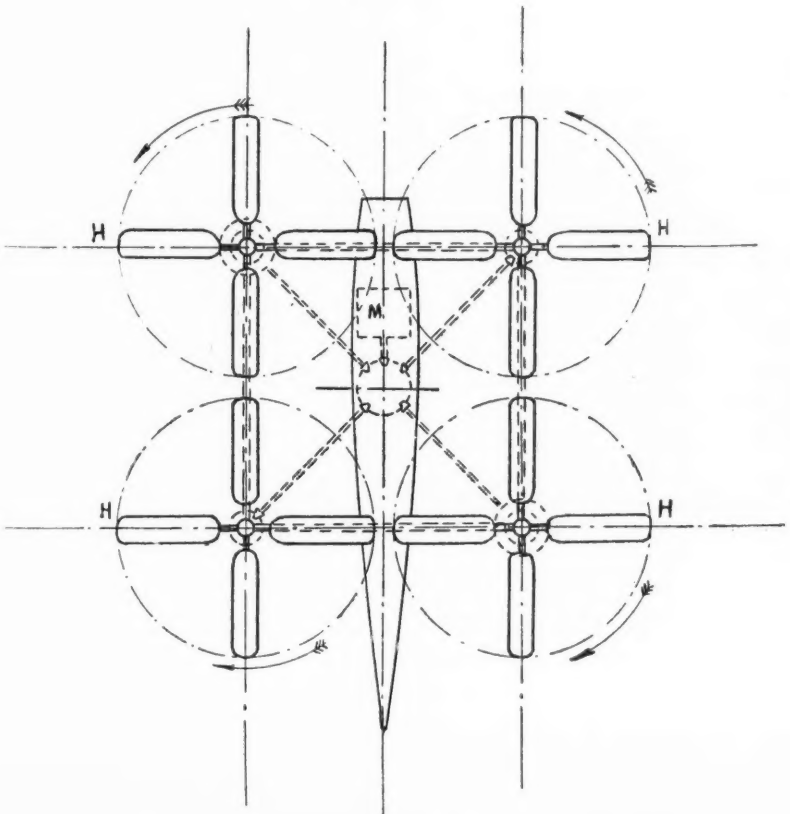
The large supporting surface obtained by this arrangement and the low motive power which should be necessary to lift a given weight, naturally led the investigations on this system.

Some interesting flights have been realised, but they have not gone beyond the experimental stage.

In my opinion the principal reasons for this were the following:—

(*a*) Highly complicated mechanical system.
(*b*) Excessive weight of the framework.
(*c*) Lack of stability of the machine.
(*d*) Very delicate mechanical transmissions.

Fig. 1



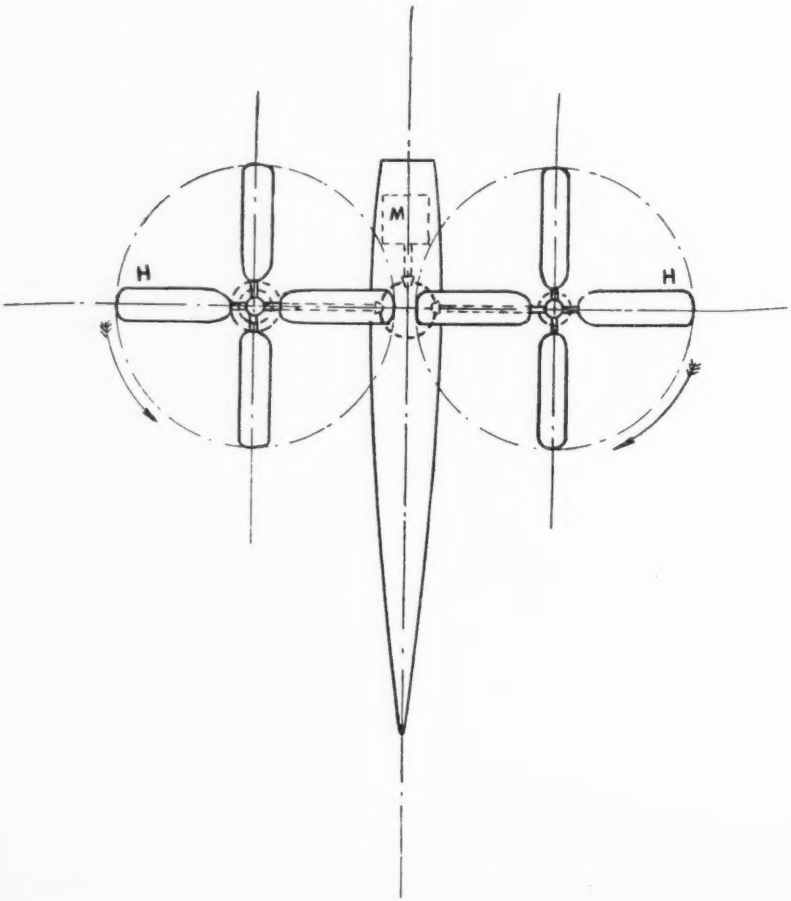
NOTE.—*The two right-hand arrows should be reversed in direction.*)

For instance, in Fig. 1, the transmissions of the power of a central engine (M) to four sets of wings of a comparatively large diameter, and at some distance from the centre of the machine, presented a very delicate mechanical problem. The necessary gear reduction from 1/12 to 1/18 was considerable and caused heavy strain on the gear teeth and in the framework. Either the gear teeth or their supports had to give way under the strain of failure or backfiring of the engine.

Moreover, the weight of the supports and of the transmissions finally encumbered the machine to such an extent as to nullify the advantage of the large supporting surface of the four sets of wings.

And again, as these sets of wings turned round, two by two, in opposite directions (so that their effect in the framework might counteract each other and

Fig. 2.



thus prevent the fuselage rotating) the gyroscopic stability of the sets of wings which might have given a certain inherent stability to the machine was destroyed.

Certain machines (Bothezat) provided for an inherent inclination of the sets of sustaining wings to remedy this fault. The correction was too feeble and thus the instability was still not eliminated.

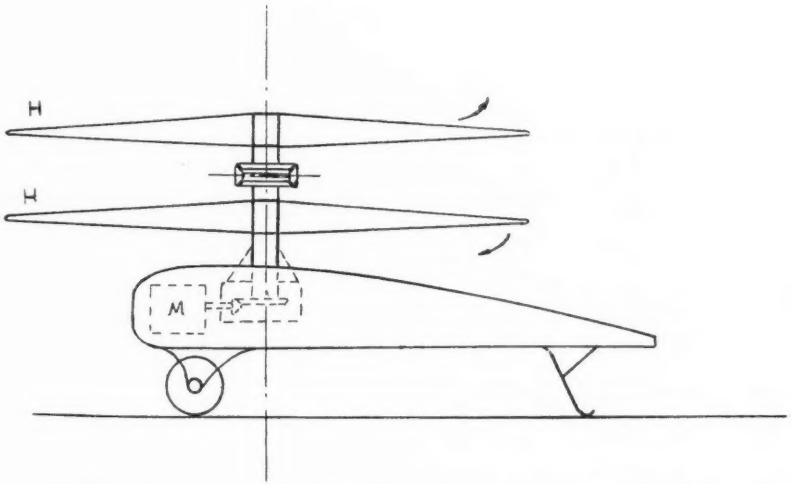
(2) *Machines with Two Sets of Sustaining Wings on Separate Axles or on a Single Axle*

These machines, so far as outline goes, rather resemble the aeroplane.

In the machine with two sets of wings on separate axles (Fig. 2), the mechanical transmissions were already simplified compared with previous machines. But for all that, the drawback just mentioned was not eliminated.

In machines with a single axle (Berliner, Petrozcy, Pescara, Douheret) breakage in the gears and of instability still remained and with even greater acuteness.

Fig. 3.



A mechanical transmission held good, on the average, for two hours, and the stability degenerated into acrobatics.

The least gust of wind made the machine lean over; the pilot had to keep continually correcting it, had to keep up a constant manipulation to get equilibrium, without success, being finally obliged to land. The arrangement of the sets of wings turning in opposite directions made the instability of these machines very dangerous.

In spite of this, this arrangement of the wings was considered indispensable, for two reasons:—

(1) To nullify the reaction of the wings on the framework.

(2) To avoid the machine turning over when in horizontal translation the forward motion creates a marked tendency for overturning.

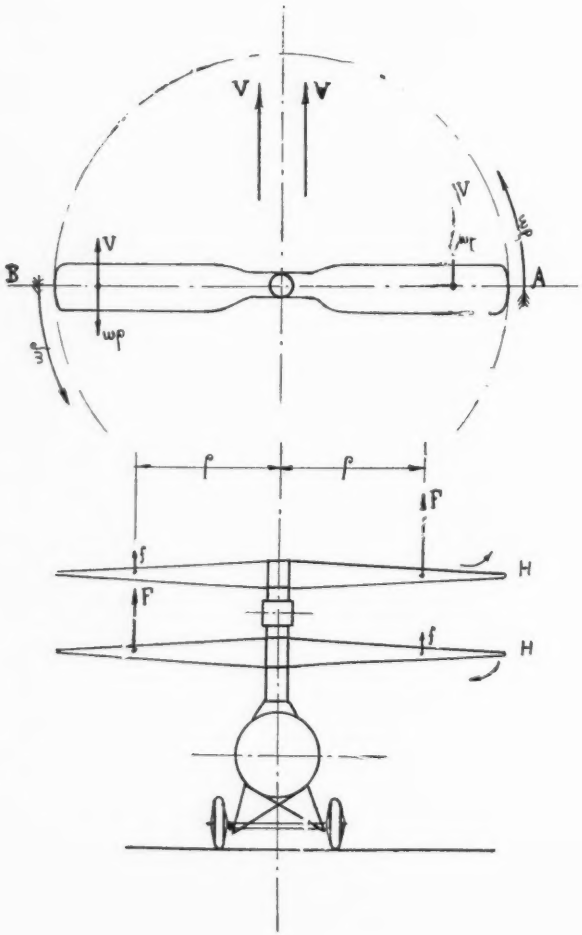
In fact, when one of the wing blades finds itself in region (A) (Fig. 4) the speeds of rotation ($w\rho$) and of advance (V) add to each other and create a strong pressure (F).

On the other hand, when the blades are in (B), the speeds are in opposite directions, the result in pressure (f) is very low. It therefore produced a very strong couple $(F-f)\,\rho$, likely to overturn the machine.

This couple could only be destroyed by the lower set of wings, which turned in the opposite direction, creating in this way an opposite and equal couple.

Apart from this instability the mechanical complication entailed such a weight of parts, frames, supports, etc., that they had to reach a horse-power of about 180 to lift one person.

Fig. 4



It is these machines, however, that have accomplished the best performances up to the present time.

(3) *Aeroplane Helicopters*

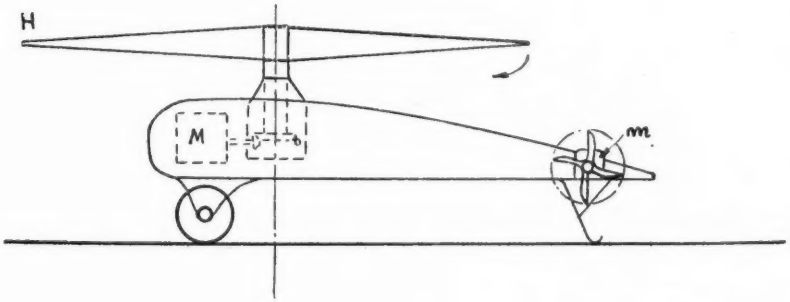
These machines (Descazes, Berliner, etc.) had not only the drawbacks of being unstable, heavy, complicated, and mechanically delicate, but possessed, moreover, auxiliary fixed surfaces to help sustentation when in translation.

The result was an extra weight serving no purpose, which prevented their making any encouraging performance.

(4) *Helicopters with One Set of Sustaining Wings Driven Mechanically*

The continual tendency of the inventors to reduce the number of sets of sustaining wings is very marked. They had realised that having a large supporting surface did not compensate for the mechanical complications and the extra weight which it entailed.

Fig. 5.



Also the instability of the machines with two or four sets of wings turning in opposite directions having been demonstrated in practice, there remained no other solution but that of *the single set of sustaining wing of a large diameter*. Consequently machines of this type have been built (Baumhauer, Chauviere) (Fig. 5).

Even though the inherent stability of these machines is greater, the mechanical difficulties remain very much the same, with still the possibility of breakage in the gearing.

To avoid the rotation of the fuselage Chauviere has recourse to a compensator and Baumhauer has a tractor screw driven by an independent engine (m) (Fig. 5) and fixed at the back of the fuselage.

In the case of the above examples, the mechanical solution would seem difficult, whilst in the second the increase in the weight is no advantage at all and, in addition to that the dangers attendant on gear transmission are still present.

Résumé

It would seem, then, from the brief criticism that I have just made, that all helicopters experimented with up to the present time have failed in principal for reasons of instability and mechanical transmission.

The analysis leads us to the conclusion, moreover, that the solution of two or several sets of wings turning in opposite directions is no solution at all and that the only way out is to have *one single set of sustaining wings but without mechanical transmission*, from the engine in the fuselage.

We therefore come to the solution *of the transmission of power by engines fitted directly on to the wings* and going round with them.

III. Aerodynamic Analysis of a Single Sustaining Propeller in Horizontal Translation

But in this way the problem is not yet completely solved.

As has been described above, when in horizontal translation, the single sustaining propeller, and therefore the whole machine, is subject to a very strong couple tending to overturning (Fig. 6).

In position (A) the speeds of rotation ($w\rho$) and of translation (V) combine on the wing and give rise to a pressure F proportionate to $(V+w\rho)^2$. In (B) these speeds are in the opposite direction and the resulting pressure (f) is very low and proportionate to $(w\rho - V)^2$.

The couple tending to overturning $-(F-f)\rho$ is considerable, and no amount of manipulation on ailerons could destroy it.

In the illustration we have imagined the overturning couple as acting on a plane passing through AB. In reality, the wing, forming a gyroscope, the reaction will take place on a plane practically perpendicular.

To counteract this serious drawback a solution has been thought out, other than that of having a second set of wings turning in an opposite direction.

The wings have been mounted with such an incidence (negative at the ends and positive in the centre) that the pressures in the regions (A) and (B) are equal for a determined speed of translation.

From the aerodynamic point of view this solution is very bad, and even, with (V) and $w\rho$ at different values, the couple was only partly destroyed.

The idea has also been conceived of varying periodically the incidence of the wings, at the pilot's discretion, in such a way as to destroy this couple. The mechanical complication which would result from this would of itself condemn the method, to say nothing of precessional movements and reactions on the framework caused by the gyroscopic reactions of the wings in rotation.

As is seen, the use of rigid wings in a single sustaining propeller brings also difficulties.

Happily this difficulty is removed by the use of wings, articulated separately in all directions at the point of their fitting in the common hub turning around the central shaft.

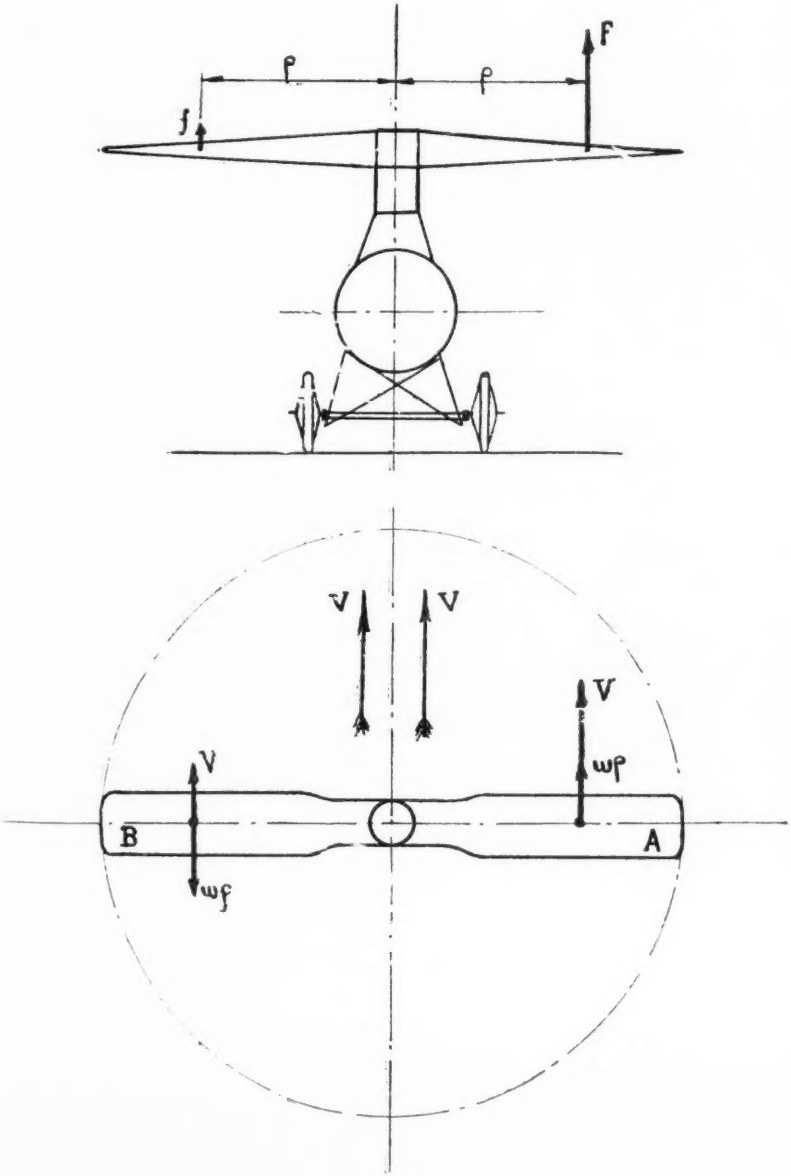
Wings articulated in this manner cannot transmit to the machines the strong couple to which they are subject in horizontal flight.

The wings will take inclinations above the horizontal plane corresponding to the force of the thrusts, the centrifugal force (or rather one of its components) coming automatically into play not only to limit this inclination, but moreover to put the wing back into its normal position of equilibrium as soon as this overpressure has ceased.

In translation the wings being subject, as we have seen, to a periodical variation of pressure. This gives rise to corresponding periodical oscillatory movements or flapping, which, however, will become proportionately of less amplitude (as the weight of the wing and its parts increases) or as the number of revolutions increases. The same applies to the direction of drag.

It is not incumbent on me, especially as time is limited, to give the exact theory of the destruction of all overturning couple by means of the articulation of the wings.

Fig. 6.



A famous inventor, the first to have carried out important flights with a machine having a revolving set of wings, has already proved it in practice.

I am referring to the Autogyro of La Cierva, and I am happy to be able to render here all the homage due to his high merit.

It will be sufficient just to say that on each wing the pressure is continually balanced by the total weight of the wing plus the normal component of the centrifugal force on that plane, and the drag by the component on that plane of that same centrifugal force.

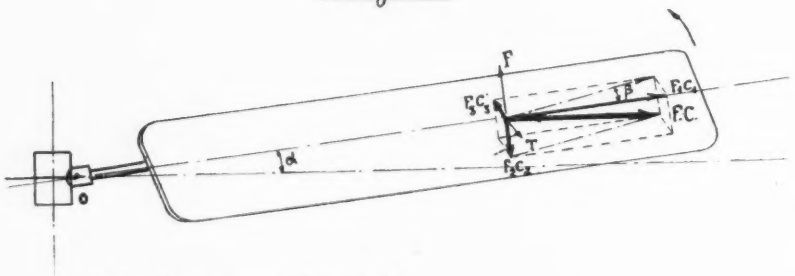
For example, let us consider a wing of a total weight (P) turning at an angular velocity ($w\rho$) and subject to pressure (F) and drag (T); the total centrifugal force:—

$$FC = (P/g)\, w^2 R$$

(R being the distance from the centre of gravity to the axis of rotation) splits up in three directions (Fig. 7).

1. $F_1C_1 = FC \cos \alpha \cos \beta$ following the longitudinal axis of the wing.
2. $F_2C_2 = FC \sin \alpha$ normal to the wing, and
3. $F_3C_3 = FC \cos \alpha \sin \beta$.

Fig. 7



Centrifugal force, $FC = Mw^2R$.
Axial component, $F_1C_1 = FC \times \cos \alpha \times \cos \beta$.
Perpendicular component, $F_2C_2 = FC \times \sin \alpha$.
Component in direction of motion, $F_3C_3 = FC \times \cos \alpha \times \sin \beta$.

$$FC = (F_1C_1^2 + F_2C_2^2 + F_3C_3^2)^{\frac{1}{2}}$$

3. $F_3C_3 = FC \cos \alpha \sin \beta$—opposite to the drag on the plane of the wing. (α and β are the inclinations which the wing takes above the horizontal and behind its resting position, respectively under the force of the pressure F and drag T.)

The angle (α) is determined when the pressure F = weight (P) plus the component (F_2C_2), and the angle (β) when the drag T = the component F_3C_3 (Fig. 8).

We have supposed these forces applied all to one point.

Generally this is not the case.

The angle (α) is found when the moment at the point of articulation (O) of the pressure (F) is equal to the moment at that same point of weight (P) plus the component (F_2C_2).

Thus, $Mo\,(F) = Mo\,(P + F_2C_2)$, and the angle ($\beta$) $Mo\,(T) = Mo\,(F_3C_3)$ (Fig. 9).

In cases of over pressure the wing will take an inclination (α') so that again $Mo\,(F') = Mo\,(P + F_2C_2)$.

In the example given in Fig. 8 there will be left only one tractive thrust on the wing equal to FC, and in the example in Fig. 9 a tractive thrust equal to F_1C_1 and a low bending moment between the resultants F and $(P+F_2C_2)$, this moment being nil at the articulation O.

Thus we have got well away from the over pressures to which the wings of aeroplanes are subject.

The articulated wing not only eliminates the danger of the machine turning over in the event of over pressure, but gives to the machine itself an automatic stability, and in addition to that allows the adoption of wings much lighter than those of a corresponding aeroplane.

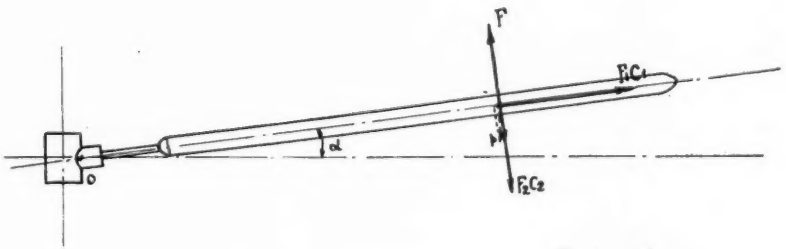
To sum up, the chief point to consider is that the single set of articulated sustaining wings eliminate at the same time both the couple of overturning and the gyroscopic reactions which would certainly occur in translation with similar wings if they were rigid.

The problem, as it has been put previously, seems now to have been solved.

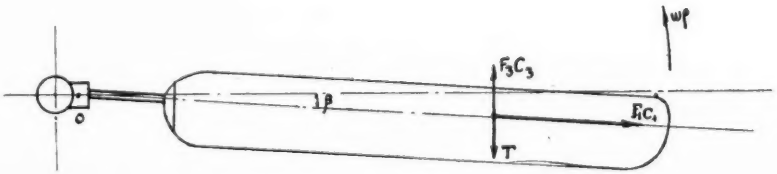
In my opinion, the problem of vertical flight will be solved by the machine that embodies the following principles:—

(1) Single set of sustaining rotatory wings of a large diameter.
(2) Each wing to be articulated in all directions at the central hub.
(3) Elimination of all mechanical transmissions by the use of engines mounted directly on the wings.

Fig. 8.



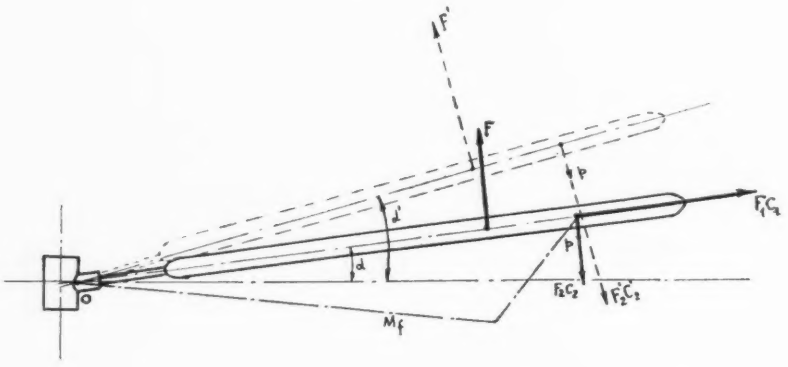
$F = P + F_2C_2$



$T = F_3C_3$

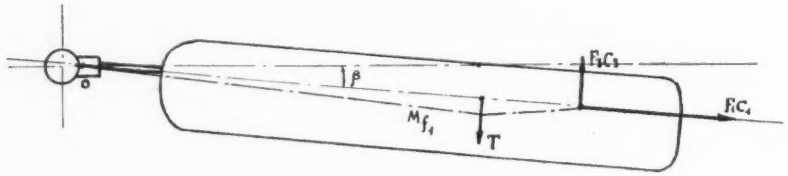
These requirements are fulfilled by the machines that I have called "helicogyres," because the rotation of the wings is assured by propellers controlled directly by small engines mounted on each of these wings, at the reverse of the autogyros, where the rotation of the wings is assured by no mechanical means except by the reaction of the air when the machine is animated by a certain speed of translation or of descent.

Fig. 9



$M_0F = M_0(P + F_2C_2)$

$M_0F' = M_0(P + F_2'C_2')$



$M_0T = M_0(F_3C_3)$

I shall describe further on the real "helicogyre flight" of which I believe myself the originator, and which is clearly distinct from "helicopter flight" and from "autogyro flight."

IV. Helicogyres

Helicogyres are machines capable of rising and of descending vertically, of remaining at any given point in mid-air, and of flying in horizontal translation. This includes helicopter flight (Figs. 10 and 11).

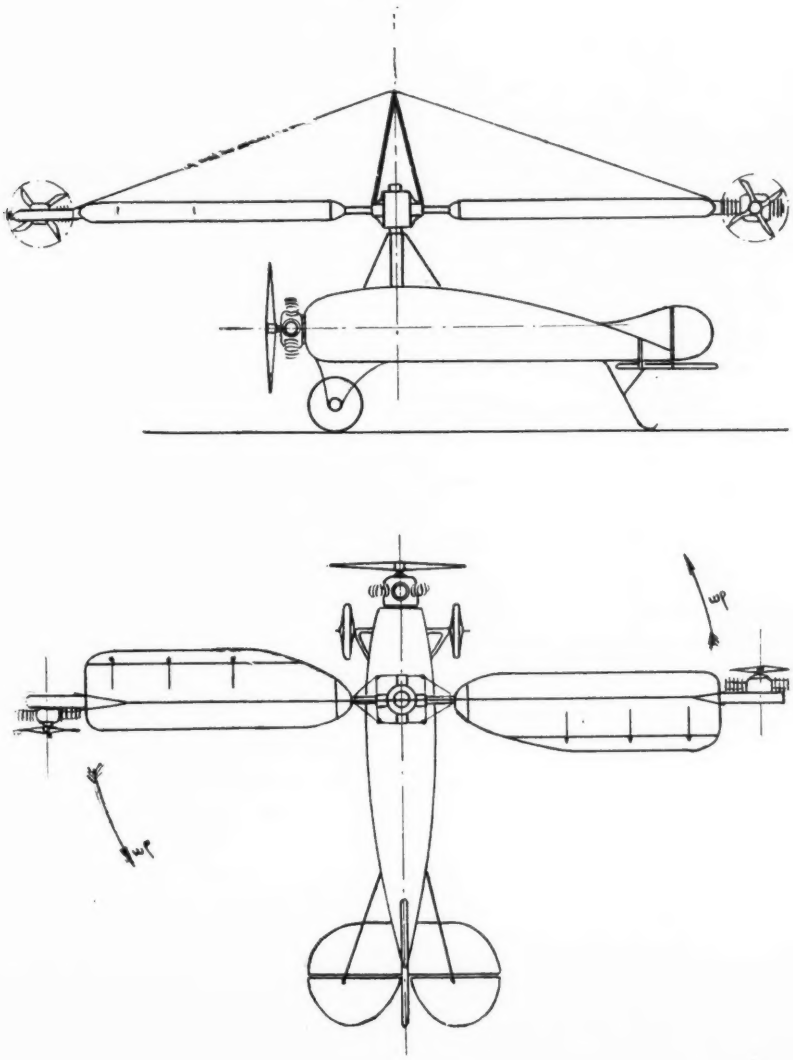
They are characterised in that—

(1) They do not involve the least gearing or mechanical transmission.

(2) The system for sustentation is entirely independent of the system for propulsion.

(3) The system for sustentation consists of two or several wings, individually articulated in all directions to a common hub, turning

Figs. 10 & 11



freely round a practically vertical axle. At the end of each of these wings are mounted small engines with their screws to cause the rotation of the wings in all normal conditions of flight.

(4) The propelling system is constituted by engines mounted on the fuselage, this fuselage being equipped like aeroplanes with an elevator and rudder.

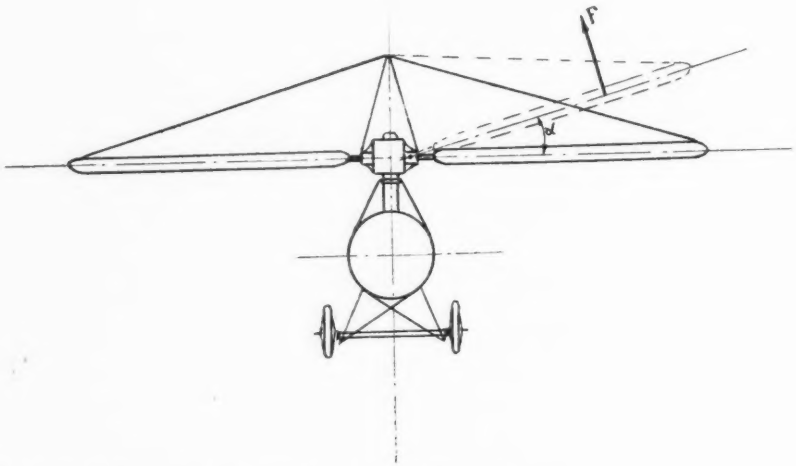
(5) The wings of the sustaining system have their incidence regulated to the wish of the pilot, by means of ailerons forming part of their trailing edge.

(6) The stability of form is assured by the articulation of the wings, and the controlled stability by the manœuvre of the elevator and rudder, and also by the small ailerons, firmly fixed to the machine, and fitted between their main wings.

(7) The petrol and oil feeds of the engine mounted at the ends of the wings are separate for each engine, the petrol and oil tanks being fitted inside the wings.

I have just said what "helicogyres" are, but there still remain a few adopted principles to be justified other than those analysed above.

Fig. 12.



(*I*) *Articulation of the Wings in all Directions*

To my knowledge, the helicogyres were the first machines having a revolving set of wings which were articulated in all directions at their common hub.

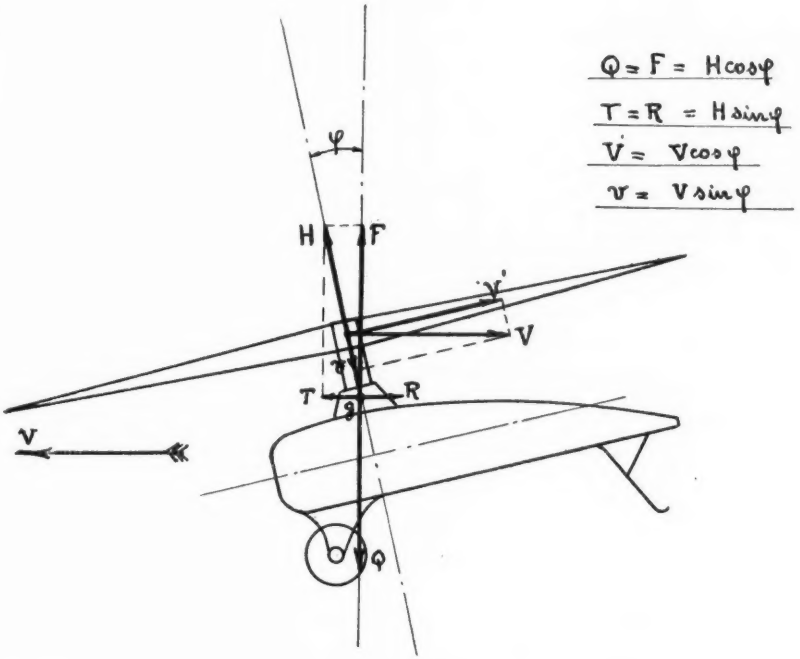
Not only in direction of the pressure is this articulation necessary to eliminate the possibility of the machine overturning, by the fact that the wing gives way to any over pressure and does not communicate any perceptible couple to the body of the machine, but also in the direction of drag this articulation is as necessary, so that when in translation, the wings do not break off at their point of joining with the central hub under the periodical variation of the force of the drag. We are pleased to see that the present autogyros are also provided with the double articulation.

(2) *Variation of the Incidence of the Wings*

To make the helicogyres adaptable to the different conditions of flight (fixed point, vertical rising and descent, horizontal and oblique translation, gliding, etc.) it is necessary that the pilot should be able to regulate the incidence of the wings.

This variation is easily effected, aerodynamically, by means of ailerons forming part of the trailing edges of the wings. These ailerons act like the elevator of an aeroplane.

Fig. 13.



(3) *Horizontal Translation*

I will now try to sum up the reasons why I have decided to adopt a totally independent system of propulsion for the translation of the machine.

The two systems generally employed are:—

(*a*) By inclining the axis of the sustaining wings or of the machine itself.
(*b*) By installing an independent engine.

(There exists a third system, "the rowing flight," but which is of no practical interest.)

(*a*) *The flight by inclination of the axis of the set of wings* is the least to be recommended from the aerodynamical point of view.

Calculations, although unfortunately too long to make here, would prove it very clearly. I will, however, try to show the underlying reasons.

Let us suppose a helicopter in horizontal flight at speed V, and inclined from the vertical at an angle (ϕ) (Fig. 13).

The pressure (H) of the sustaining propeller will give rise to two components:—

1. F—equal to and opposed to the total weight (Q) of the machine, and
2. T—equal to and opposed to the total resistance (R) to translation of the machine.

The speed of translation (V) will also give rise to two components:—

1. V' on the plane of rotation of the propeller, and
2. (v) on a plane perpendicular to the above, that is to say, following the axis of the set of wings. *This component will be the cause of the low efficiency of this system.*

Let us now consider the wings during their combined movement of rotation and translation (Fig. 14).

One section (m) of the wing, at the time of its passing point (A), is subjected to velocities ($w\rho$) and (V'), both in the same direction and both on the plane of rotation of the wing. The component (v) with speed ($w\rho + V'$) will determine the resultant (U), of which the angle (i_1) with the cord (CC') of the part will be the real angle of attack (Fig. 15).

In the case of the section m_2, nearer the centre of rotation, the speeds (V'' and (v) remain the same; it is only the speed of rotation ($w\rho$) which is much lower. The real angle of attack (i_2) will be much lower (Fig. 16).

Of course, the wing which we have been taking as our example is a flat one, that is to say, having no pitch.

The real angle of attack (i) is therefore different for all the parts of the wing when it is in the position (A).

When the wing is in the position (B) the variation of the angle of attack (i) is going to be still greater.

For a section (m'_1), the speeds ($w\rho$) and (V') are in the opposite direction, the angle (i_1) will be negative (as shown), or very slightly positive (Fig. 17).

For part (m'_2) the angle (i'_1) will be much more negative (Fig. 18).

Thus, it is clear that when the set of wings is inclined in the direction of advancement, the real angles of attack vary continually for each part of the wing and for each position in space. These angles of attack go from extreme positive values to extreme negative ones (approx. $+60°$ to $-150°$), and the average aerodynamic efficiency of the wing, or more exactly, the relation of the total pressure to the total drag, is very much lower than that of a corresponding aeroplane at equal speed.

Having studied at length several examples of translation, I may say that the relation of the pressure to the drag is from 40 to 50 per cent. lower than that of an aeroplane under the same conditions.

This solution, therefore, does not appear to me to be one to be recommended.

We have expressly considered rigid wings. Although, with articulated wings, the flapping changes favourably the incidence of the various elements of the blades, the qualitative value of the comparison is not altered.

(*b*) *Translation by independent engine.*—Solution No. 1 being rejected, it is now left to consider adopting translation by means of an independent engine mounted on the fuselage.

I will demonstrate briefly that this system of translation permits of an aerodynamic efficiency comparable to present-day aeroplanes.

The axis of the machine remaining vertical, the speed of translation (V) lies on the plane of rotation of the wings.

The small very undesirable component (V) which we found in the previous case is eliminated.

Fig. 14

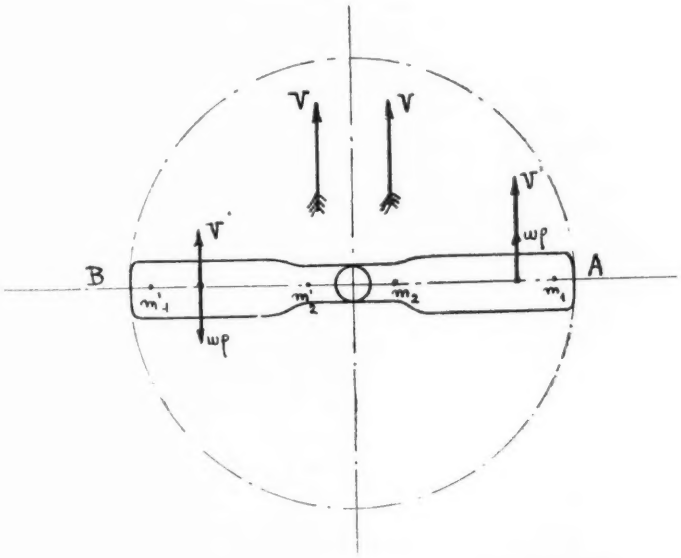


Fig. 15

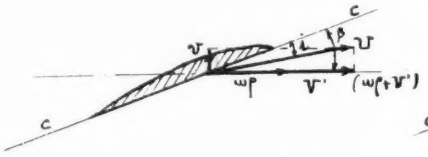
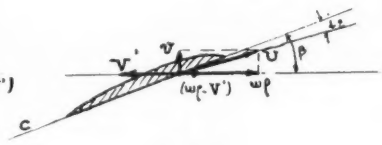


Fig. 16.



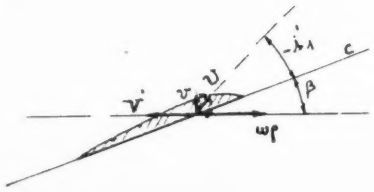


Fig. 17

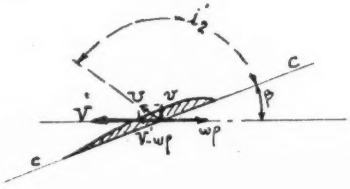


Fig. 18.

Let us consider again the wings in the positions (A) and (B) (Fig. 19).

For all the sections from m_1 to m_2 of the wing at position A, the real angle of attack, (i) is everywhere the same. It is therefore the same as with an aeroplane (Fig. 20).

Fig. 19.

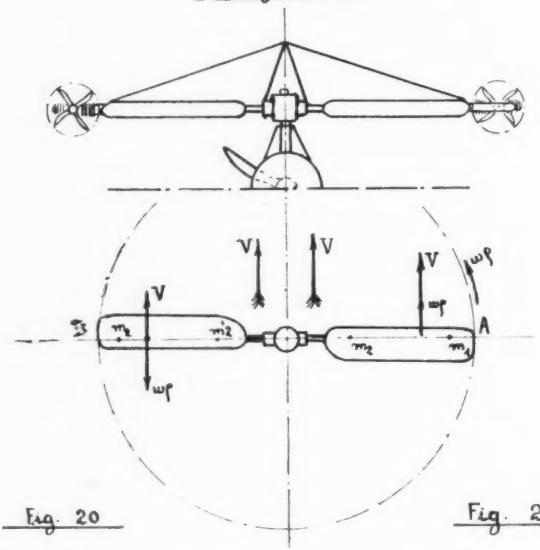


Fig. 20

Fig. 20

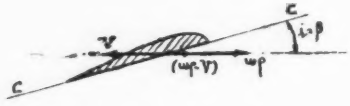


Fig 21

Fig. 21

For position (B) the angle (i) will also be the same so long as $w\rho$ is greater than V only when $w\rho$ is less than V will the angle (i) be of the same value, but negative (Fig. 21). Therefore it is only a part of the wing where the lifting capacity is small, and at a position in space where the pressure is lowest, that the angles become negative. An exact calculation will show that altogether, the relation of the pressure to the drag is in this case very little different (about 5 per cent,) from that of an aeroplane with the same profile and angle of

incidence. The flapping of the wings (whose amplitude is much lower than in the autogyro on account of the weight of the engines, tanks, fuel, etc., . . .) will in reality alter slightly the incidence of the blades.

Helicogyres, owing *to their keeping the axis constantly vertical*, are those of all the types of machines with revolving wings, whose efficiency is most comparable to that of the aeroplane.

(4) *Stability of Helicogyres*

One of the essential conditions for a vertically-flying machine is that it should possess :—

(*a*) Stability of form or inherent stability, and
(*b*) Controlled stability.

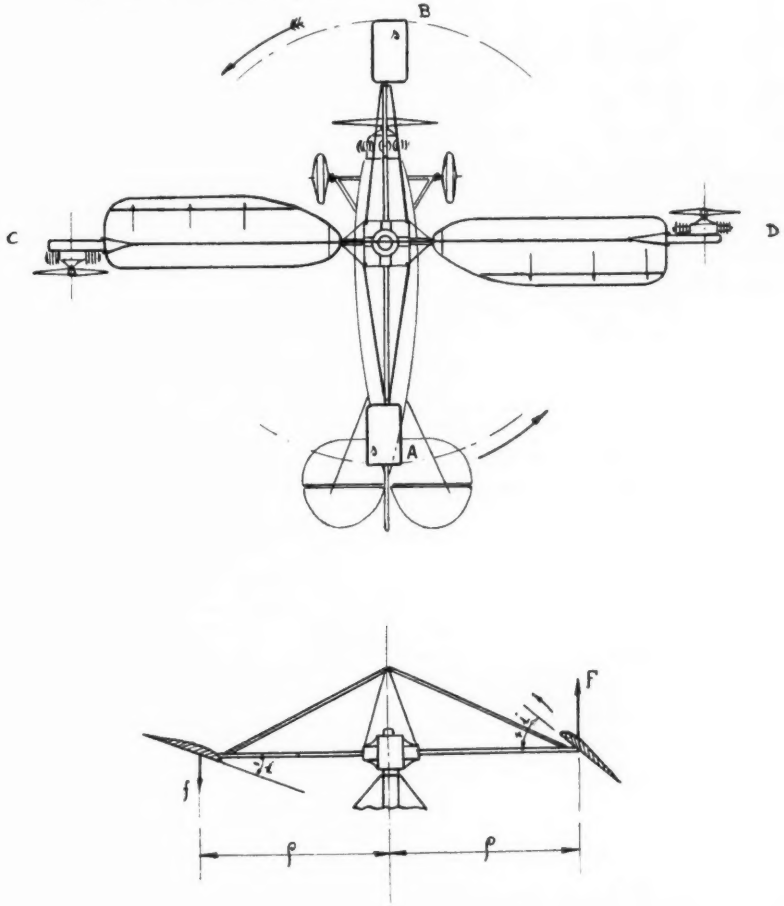


Fig. 22

(*a*) I have shown above how controlled stability is in itself not sufficient when the machine is standing still in mid-air. It is therefore indispensable that the machine should possess inherent stability to enable it, without any intervention on the part of the pilot, to regain its original position if for any reason it should have been driven from it.

Thanks to the articulation of the wings, helicogyres possess this inherent stability. I hope I may be given an opportunity later of giving you my personal theory of the automatic stability of helicogyres.

(*b*) For the controlled stability, particularly necessary at the moment of leaving the ground and of landing, helicogyres are provided with small surfaces (*s*) fitted between the principal wings and firmly attached to the machine (Fig. 22).

By moving the central hand lever it is possible to make either transversally or longitudinally, a periodical variation in the incidence of these surfaces, so that the required rectifying couple, longitudinal or transversal, may be made.

The stability controlled by this system will be at least as efficacious as that of an aeroplane.

In horizontal translation the controlled stability, if necessary, will be assured by the same surfaces, and also by the elevator and rudder, fitted on the fuselage.

(5) *Position of the Engines on the Wings*

Which would be the best position on the wings for the engines?

There are several problems to be taken into consideration in detail. But I will only state a few of the reasons why the *end of the wing* is preferable, on account of the higher speed at this part of the wing.

(*a*) The efficiency, when standing still in the air, and in rising, of the tractor screws driven by those engines, will be much greater.

(*b*) The undesirable effect of the speed of translation on the efficiency of the tractor screws driven by these engines and on the speed of rotation of these latter, will be considerably reduced.

(*c*) The oscillations of the wings due to the periodical variation of pressure and drag in the translation will be much reduced.

(*d*) The mounting and the superintending of the engines will be simpler.

(*e*) It will be possible to use engines running at 4,000 to 5,000 r.p.m., which represents an appreciable advantage over aeroplanes.

V. Comparison of Helicogyres with Aeroplanes

If helicogyres are to claim first place in aerial navigation, it is not enough just that they should be able to fly.

It is necessary that they should have all-round qualities comparable to those of present-day aeroplanes.

We will therefore analyse them from the point of view:—

1. Of the weight lifted per horse-power.
2. Of performances in horizontal translation.
3. Of safety in flight, of safety in case of partial or total failure of the driving power.
4. Of safety in landing.
5. Of fatigue of the various parts.
6. Of its commercial qualities.

(1) *Weight Lifted per Horse-power*

The power required for the sustentation of the helicogyres we have built has been less than what was expected.

The thinness of the monoplane wings, and the relatively large diameter of the rotatory wings, have enabled my experimental machine No. 1 to lift 1,875 lbs. at 100 h.p. on the wings, in spite of the fact that the engines (two Anzanis of 50 h.p.) were nearly in the middle of the wings, and therefore that the efficiency of the tractor screws driven by these engines did not exceed 60 per cent.

My machine No. 2, with two wings, each fitted with a 32 h.p. Bristol Cherub engine right at the end, and having a total weight of 1,320 lbs., rose several times from the ground by only utilising 50 h.p.

This represents about 26.5 lbs. per unit of horse-power.

With four wings on a machine of the same weight, we think we could easily reach about 30 lbs. per h.p., which figure would easily be exceeded in the future with wings of more appropriate shape and section.

Further, if the front engine is used—that is to say, if the machine runs a few yards along the ground—the weight lifted per horse-power will be still greater.

I am of opinion that helicogyres will be able to lift at least the same loads as present-day aeroplanes.

(2) *Horizontal Translation*

It would obviously be too long to give an exact comparison of aeroplanes and helicogyres when in translation.

Working on the fairly accurate calculations which I have already referred to, I am of opinion that the efficiency of helicogyres compares very well with that of aeroplanes, everything being equal. From an aerodynamic point of view, it approaches the aeroplane within five to seven per cent.

But other advantages militate in favour of the helicogyres, which will enable them to reach and even to improve on the performances of aeroplanes in horizontal translation.

The lightness of the wings, whose sole principal fatigue is traction, and of the fuselage, which does not suffer violent shocks on landing as happens with aeroplanes, and the elimination in the future even of this undercarriage, are advantages which will more than compensate for the very small difference of efficiency when comparing with the aeroplane.

(3) *Safety of Flight*

As regards safety of flight, I am of opinion that none of the existing types of flying machine possesses it to the same degree.

In the first place, by virtue of the articulation of the wings the machine is automatically stable. Hence no danger of overturning, and therefore easier piloting.

In the event of failure of some of the wing engines, the remaining ones will be sufficient to assure the rotation of the wings. In fact, it is well known that the efficiency of a sustaining propeller increases under a feeble current of air—or in other words, in translation at even a low speed.

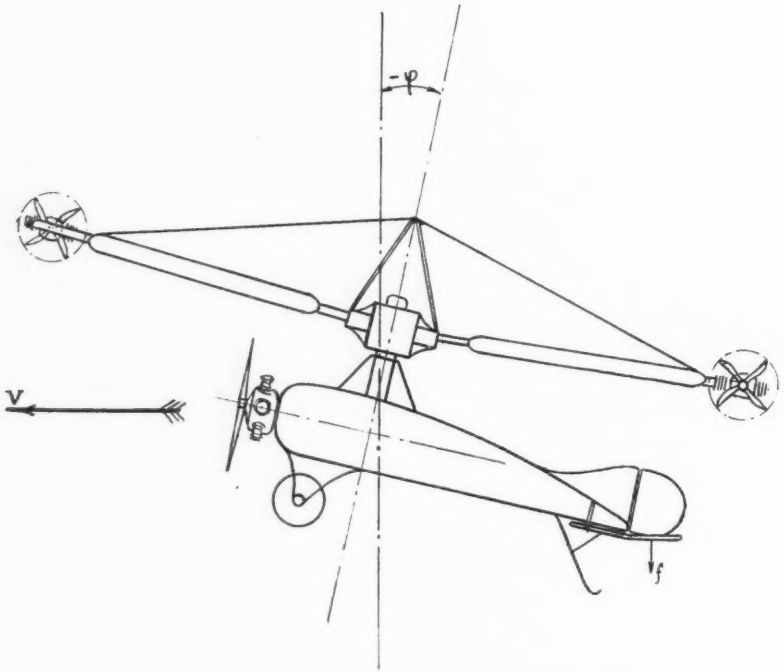
In the event of the failure of all the wing engines, the machine can continue its flight on the autogyro principle at a reduced speed. The pilot has only to incline the axis of the machine slightly backwards from the vertical (Fig. 23). This, of course, would be an extreme case, as it is highly improbable that all (usually four) of the wing engines would go out of action at the same time.

Neither would the failure of the front engine prevent the continuance of translation, although the speed of it would certainly be reduced. By inclining

the axis of the machine a little forward, the wings will serve both for sustentation and propulsion (Fig. 24).

Only in the event of the failure of every single engine would the pilot have to land. He may, however, glide vertically or obliquely, according to how he wishes to land.

Fig. 23.



(4) *Safety in Landing*

With the wing-engines working, the descent may be as slow as the pilot wishes. But if the descent is made by a vertical glide, the pilot may, when within two or three metres from the ground, quickly increase the incidence of the wings and thus create an overpressure by utilising the kinetic energy stored up in the wings. This kinetic energy is considerable, due to the weight of the small engines at the ends of the wings. Therefore, even with the failure of all the engines, the landing is effected without almost any shock.

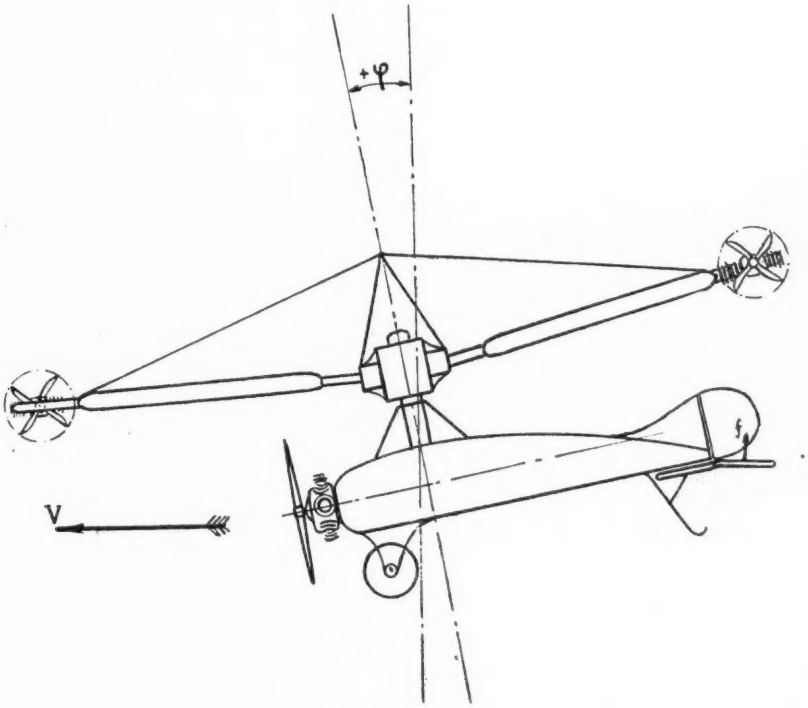
(5) *Fatigue of the Parts*

Since helicogyres do not contain any gearing, it can be claimed for them that they will last longer than aeroplanes, because:—

(*a*) The wings are principally subject to a tractive strain varying from 25 to 35 per cent., according to the condition of flight.

(*b*) Landing is effected without any shock, which means that the fuselage and other parts only suffer normal strain, without any further fatigue.

Fig. 24



(6) *Commercial Qualities*

Assuming that all that is claimed for it in the foregoing will be realised, the helicogyre will possess commercial qualities superior to those of aeroplanes.

The elimination of landing grounds, which are so costly and so far away from the centres of the towns; the safety of flight due to the automatic stability of the machine; the possibility of continuing flight even after the collapse of the greater part of the engine power; the absence of any danger either in landing or starting; and the safety derived from the fact that no part of the machine is subject to any abnormal strain, etc.—all these considerations will allow aerial navigation and aerial transport to develop to an extent unthought of at this stage.

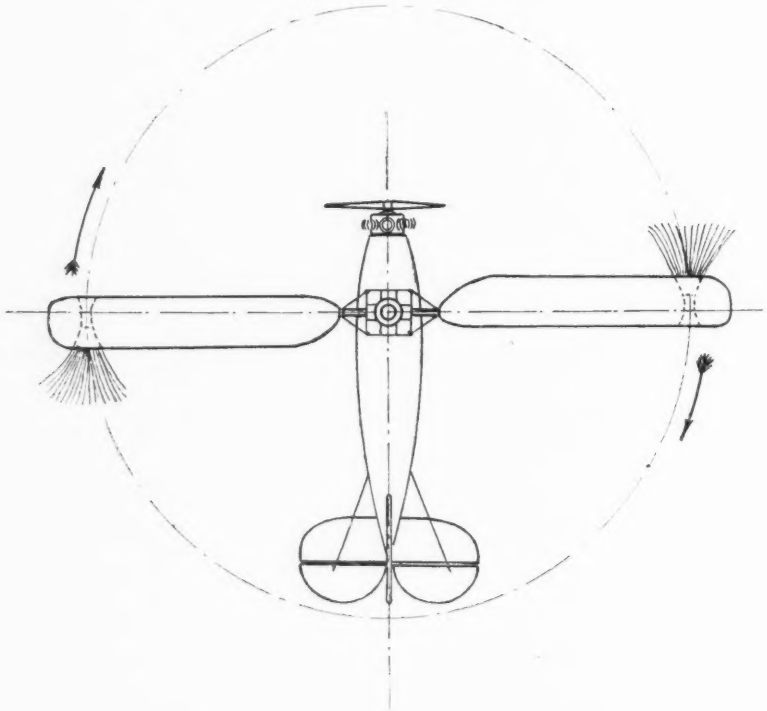
At some time in the future, jet propulsion engines (powder or continuous combustion) (Fig. 25) could be adapted to helicogyres, whereas they would be dangerous for aeroplanes.

VI. Helicogyre Flight

I have spoken of helicogyre flight as being a new mode of flight, distinct from helicopter flight or autogyro flight.

The " pure helicogyre " (that is to say, realising helicogyre flight such as will be described hereinafter) cannot remain at any fixed point in space as the helicopter can, neither does it have its wings driven by the reaction of the air on them, as in the case of the autogyro.

Fig. 25



It is identical with the helicogyre machine already described, except only in the very low power of the wing engines (about 7.5 to 10 h.p. for a single passenger machine with four wings). This low power would not allow it to remain at any fixed point in space, but it would assure the rotation of the wings, and consequently the sustentation of the machine, provided a certain speed of translation is reached.

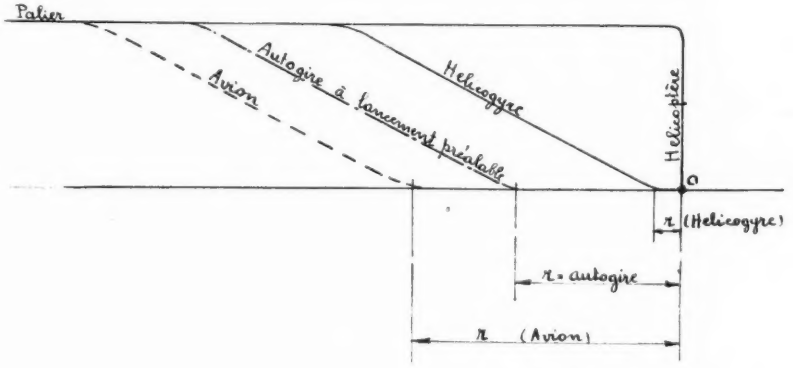
This is based on the well-known fact of the increase of the sustaining quality of propellers under the effect of a current of air perpendicular to its axis—in other words, on the fact that if a sustaining propeller absorbs a power X at a fixed point, it will absorb a much lower power (one half or one third, according to the circumstances) when at a low speed of translation.

In " pure helicogyre " flight, the springing off from the ground is practically vertical, in spite of the low power of these engines on the wings.

The pilot has only previously to set the wings, by regulating their incidence to zero, for a speed higher than that normally required. The rapid increase of this incidence of the wings will give rise to an over pressure at least equal to the weight of the machine, since the kinetic energy stored up in the wings and their engines during rotation is considerable.

The front engine must be running while this manœuvre is effected by the pilot, and then translation of the machine will immediately commence. Whilst the kinetic energy is being absorbed by the over pressure, the machine will already have attained the speed of 5 to 7 yards a second, which would be sufficient to enable the small engines themselves to continue rotation of the wings and consequently the sustentation.

Fig. 26.



Here is a diagram (Fig. 26) representing the starting off of aeroplanes, autogyros with self-starting wings, "pure helicogyres" and helicopters, to give an approximate comparison of the distance covered on the ground before taking off.

I grant that the starting up of a "pure helicogyre" will be a delicate operation and will require a certain amount of skill on the part of the pilot. The pilot, to get practice, will have first to run several yards along the ground before taking off, and thus gradually be able to take off without having to run along the ground at all.

What are the advantages of these "pure helicogyres," thus defined, over the helicogyres already described?

The advantages are:—

1. Higher efficiency in translation, since the front engine will profit by the power saved in the wing engines, whence it follows that, power and weight being the same, they will go more quickly.
2. Less weight at the end of the wing, which will allow of lighter wings.

But helicogyre flight can also be applied to helicogyres calculated to rise vertically, in the following special cases:—

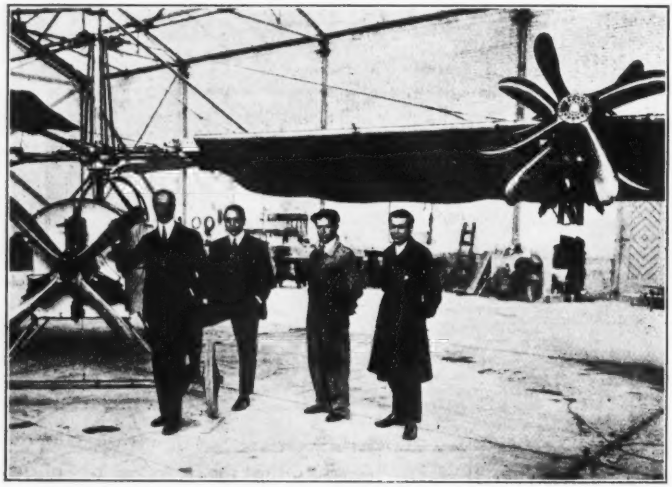
1. When a greater load has to be carried than that calculated for.
2. When for any reason two out of the four wings are out of action.

The importance of these two cases is particularly to be noted when it comes to commercial exploitation.

In "pure helicogyres" the total weight of the wings, including the small engines, will scarcely equal the weight of corresponding wings on an aeroplane.

Bearing in mind that the fuselage also will be lighter, since landing can be effected without any shock, "pure helicogyres" will have, the weight being the same, an engine power greater than that of a corresponding aeroplane or autogyro.

There is not sufficient time to develop even one of the theories which I have been privileged to put before you very briefly. I have made an attempt at giving you a very general view of the problem of vertical flight. I hope, nevertheless, that you will come to share my opinion that the successful attempts of so many inventors will one day produce the desired result, namely, that a vertical flying machine, within everybody's means, will be a reality at a not very distant date.



Details of the central pylon, one of the wings, engines and propellers of machine No. 1.

VII. First Practical Results Already Obtained with Helicogyres

Three helicogyres have been built up to the present time.

The first during 1926 and 1927, ordered by the French Government.

The second during 1927 and 1928, on the strength of a second contract with that same Government.

The third during 1928 and 1929, ordered by the British Air Ministry, at the Saunders works at Cowes.

Machine No. 1 was an experimental machine, particularly for the adjustment of the engines and the various controls. The purpose of this machine was to show that the transmission of power to sustaining wings by engines fixed on those wings was possible.

The perfecting of the parts, of the stability and the variation of the incidence has been very intricate. The fact that the engines are going round the shaft has not given rise to any difficulty, thanks to the provision of certain very simple feed arrangements.

This machine had four wings, of which only two carried engines, two 50 h.p. Anzanis, fixed about half way along the wing. In the front was a 35 h.p. Anzani engine.

This machine, with a total weight of 1,875 lbs., left the ground several times, and officially before the Commission of the French Technical Aeronautical Department on the 22nd February, 1927.

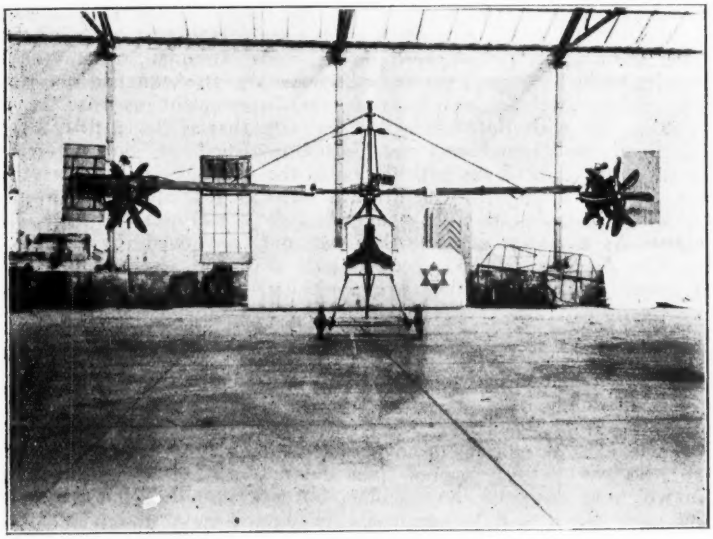
The second machine has two wings, each fitted with a 32 h.p. Bristol Cherub engine right at the end. In the front is a 50 h.p. Anzani engine.

Having a total weight of 1,320 lbs., this machine has already realised several risings from the ground, using only 50 h.p.

This is vastly different from the 150 to 200 h.p. required for the mechanical transmission systems. Besides, the front engine was not used.

Trials with this machine are still going on in France, under the supervision of the French Technical Aeronautical Department.

Machine No. 3 has only just been finished. In spite of the fact that it is an entirely new conception, it has taken Messrs. Saunders only six to seven months to build it. It is similar to machine No. 2, but it is for two persons, and has four wings, at the end of each being fitted a 32 h.p. Bristol Cherub engine. In the front is fitted a 100 h.p. Genet engine.



Special mounting used for the fitting, in rotation round a vertical axis, of the engine of machine No. 1. The wooden plates fitted were to absorb the drag during trials to show that the engines would function while moving in circular paths.

Trials with this machine are shortly to be carried out by the Air Ministry itself.

I take this opportunity openly to thank the Air Ministry for the support that has been given me and for the very close attention the departments there have given to my calculations and theories.

I firmly trust that some early trials will completely fulfil all our hopes.

Discussion

Mr. H. E. Wimperis (Director of Scientific Research): He would like to express his personal pleasure that the author had been able to give an

account of this remarkable invention. Cierva, in introducing the hinged wing, had made an advance which transformed the position of the rotating wing as a practical flying machine. Prior to the Cierva machine, no helicopter had flown a cross-country journey of even ten miles. Since then, however, we had had experience of the Cierva auto-gyro flying thousands of miles in this country, in Germany, and in France with ease and security, certainly without any accident of a serious nature. That type of rotating wing machine could descend in a very small field, but when it wanted to get away it wanted a very big field, and no way of getting over that difficulty had been discovered, although, if some mechanical starter for the windmill could be devised—and that was by no means an easy proposition—a good deal of the difficulty would be overcome. M. Isacco had realised that a further development was necessary in order to enable this type of machine to get out of a small field, as well as being able to get into it. A year or two ago the Air Ministry had the advantage of receiving the proposals and calculations of the author; these were very carefully examined, and he found a very strong opinion on the part of his staff—which he himself shared—that Signor Isacco was a competent engineer, well acquainted with the theory of the subject on which he was working. The Air Ministry's experience of the rotating wing machine went back some years to the work done by Mr. Brennan, whom the author did not refer to in his paper, probably because Mr. Brennan had not published anything. That machine was built at the Government expense at various places, ending up with Farnborough. The fact that it never flew more than a few feet off the ground was not Farnborough's fault, but purely, in his opinion, to the absence of any articulation in the wings, and, therefore, inability to obtain stability in flight. The lift was easy to get, and most inventors of rotating wing machines thought that when they had got lift they had got everything. As a matter of fact, they had only scratched the surface of the subject. The Air Ministry had spent a good deal of money and given a great deal of attention to the rotating wing machine, with results which were well known. Now there was the Isacco machine, and the possibility of making a step farther by applying power to the windmill itself. Whether the author would be able to achieve the ambitions he had in view, it was not easy to say, but certainly he had everybody's good wishes. Like Cierva—who, in undertaking the development of the auto-gyro work, became the pilot of his own machine—the author would, he gathered, be the pilot of the helicogyre, and personally he felt that all flying inventions had a better chance of success if the man who invented any one of them did not content himself with the arm chair in which he designed the machine, but got into the pilot's seat. There was one point he wished to emphasise in regard to a design of this type; the ability suddenly to increase the incidence of the blade and thereby make use of the stored energy in the rotating system, enabled very gentle vertical contact to be made with the ground, a kind of " kissing " contact, and that was entirely novel. The field of application of the rotating wing machine, however, had been greatly restricted by the work of Mr. Handley Page by his invention of the slotted wing. It was exceedingly difficult to get stability at low speeds, and the invention of the slotted wing had gone a long way to meet the difficulty, and that invention left less for the rotating wing machine to do. However, the slotted wing, splendid as it was, had not yet shown itself able to climb nearly vertically. Mr. Handley Page might have that in store, although not at the moment, he believed. There was nothing more for him to say, except this in conclusion. It was the view of the Air Ministry—and certainly one that he himself shared—that it was not reasonable that research on the fixed wing machine should go forward without clearing up as well as one could at the same time the possibilities of the rotating wing machine. One should not leave an unsolved problem like that behind. There was a practical flying machine in the rotating wing type. The stability and

other aero-dynamic features had been clearly established. The question at present was how it would compare with the fixed wing machine in top speed, rate of climb and miles per gallon of fuel; and whether the former probable performance could possibly be outweighed by the several peculiar advantages that the rotating wing machine would bring. This balance had yet to be struck.

Mr. JOHN L. HODGSON: The problem of achieving flight by means of lifting screws seemed to bear a very considerable resemblance to the problem of attempting to achieve perpetual motion by means of purely mechanical devices. During the seventeenth and eighteenth centuries frequent meetings similar to the present one must have been called, in which an enthusiastic inventor explained that the problem was at last really upon the point of solution! It was now known that the results of the search for perpetual motion were negative, and that one result of the long continued search was the enunciation of the Law of the Conservation of Energy.

He suggested that it was perhaps not too much to hope that after a sufficient number of negative results had been obtained in respect of the screw method of achieving flight, some law bearing upon the conservation of resources might be able to be enunciated.

The attraction of the screw method of achieving flight was three-fold—it promised, and actually did give, inherent stability; it offered the possibility, and at the same time most elusively refrained from giving, the power to hover and to make safe vertical ascents and descents. Now, since adequate stability could be obtained in much simpler mechanical ways than by means of lifting screws, no-one who was not lured on by the remaining possibilities would desire to fly by means of them.

A comprehensive series of tests on models of lifting propellers of all types which he had made in 1915 showed that it was impossible to rise and descend vertically with lifting screws of reasonable size unless engines of very much less weight per horse-power than were then, or are at present, available, were used. It was his opinion that in spite of small reductions in weight produced by such devices as placing the engines on the wings, and running these at increased speeds,* using lighter wings because these were articulated and so subject to less shock on landing, doing away with the under-carriage, and so on, the satisfactory solution of the screw method of achieving flight depended upon the production of these lighter engines, and even when these engines were produced, vertical ascent and descent would probably waste more energy than the average man would care to pay for.

Until the lighter engines were available, vertical ascent and descent could only be achieved by storing up additional energy in the machine as by increasing the angular speed of the wings of M. Isacco's machine before the vertical ascent or descent was attempted. In any given case where the manœuvre was not carried out sucessfully during the expenditure of the stored energy (which store must necessarily be small) disaster would probably follow—in the case cited by the previous speaker the kiss would become a blow—so that a really adequate solution of the problem of vertical ascent and descent depended upon having available at the lifting screws a continuous supply of power much greater than our present technique is able to provide. He disagreed with the previous speaker that any useful purpose was to be served in further investigating the problem, when it could quite clearly be seen that no ingenuity in design was likely to reduce the weight sufficiently to give the results hoped for with present engines. It was false to think that such experiments as the present paper described ensured that no possibility was left unexplored, as the whole problem would be transformed if more powerful engines were available.

* When working on this possibility fourteen years ago, Mr. Hodgson found that the gyroscopic forces on the propellers became of serious import.

The problem seemed to him somewhat analogous to an attempt to build a bridge with a span some 20 or 30 per cent. longer than the greatest span yet achieved. The maximum length of span possible in any given case depended upon the strength and specific weight of the material of which a bridge was made, and no ingenuity on the part of the designer would enable this maximum span to be exceeded with any given material. He therefore urged that until power plants of considerably lighter weight than those at present available could be employed, experiments on the screw method of achieving flight should be discontinued.

He further suggested that when such lighter engines were available the articulated propellers which were the basis of the Cierva and the Isacco machines would not be necessary, ingenious though they were. One would use a machine of the general type shown in the author's figure 1 with some form of automatic control to regulate the relative pulls of the lifting screws.

In 1915 the speaker had constructed a model of such a machine as that illustrated, and had " flown " it in water in order to test the difficulty of maintaining direction and balance. He had found that there was very little difficulty in so doing.

He suggested that his paper of eleven years ago* should be republished in the proceedings of the Society, so that the data therein contained should be available for those whom the screw method of achieving flight still continued to entice into essentially useless activity.

In conclusion, he would like to repeat the last paragraph of the 1917 paper, which was as follows :—" The most practical solution of the helicopter problem seemed to be that shown in Fig. 24, where two aeroplanes circle round an observation car, which, by means of gearing, is prevented from rotating. This solution of the helicopter problem, while eliminating most of the difficulties above enumerated, did not seem sufficiently promising to be worthy of further development."

The machine described in M. Isacco's paper was this idea applied to the Cierva machine. While flight by the means proposed by M. Isacco was interesting, as adding still another way of getting into and moving about in the air, it did not seem likely to replace the gliding method which was at present so well established.

Mr. McKinnon Wood : He was inclined to disagree with the last speaker, who seemed to suggest that more h.p. per lb. was required for progress in aeronautics. He would rather say that a restriction of h.p. was wanted to encourage aerodynamic progress. Mr. Wood expressed Mr. Glauert's regret that he was unable to attend the lecture, and remarked that Mr. Glauert had made a closer study of the theory of helicopters, and was more able than he to discuss this subject. Referring to the author's account of his reason for distributing the power partly in the rotating system and partly in a unit in the nose, the speaker said that he had been able to follow the argument only in so far as it related to a fixed airscrew. M. Isacco's blades were, however, intended to flap. Even with reference to fixed blades, it seemed that an important factor had been omitted, namely, what was called in airscrew theory the inflow, and, more generally, the induced velocity. The introduction of this factor might considerably modify M. Isacco's conclusion. Leaving that point out of discussion, however, he could agree that if an airscrew had blades set at a constant angle to its plane of rotation and moved in its plane of rotation, the incidence would everywhere be constant, and that if it were tilted the incidence would vary. The designer of the helicogyre had, however, hinged his blades so that they should flap up and down and change the incidence in order to compensate for the change of speed of the relative air-flow as the blade went round and so to annul the large rolling moment which would arise

* See Proc. Inst. Automobile Engineers, 1917. Partly reprinted at end of the discussion.

from the changes of speed if the incidence remained constant. The incidence must, in fact, vary in such a way as to annul this moment, whether the plane of rotation were horizontal or tilted, and he could see no essential difference. The blades athwart the direction of flight seemed to be acting under identical conditions in either case. There would be a difference in the fore and aft positions, but that did not affect the incidence. He thought the author was a little optimistic in his comparisons of the helicogyre with the aeroplane. If one worked out simply the theory of a system of rotating wings, one might conclude that the aircraft with this system could never climb so fast as an aeroplane, but might fly as fast on the level. But the theory would be leaving out of account what was happening at the hub, by which he meant a region extending some little way along the blades. He could not imagine that it would ever be possible to make a helicopter or autogyro anything like as clean in design as an aeroplane. Many of those present might have questioned the author's suggestion that the helicogyre could be put down more gently than an aeroplane. Experiments had shown, however, that even when an aeroplane had made the most perfect landing and had taxied in, the acceleration experienced was between 2g and 3g, and that was due to the horizontal velocity of the aeroplane and the unevenness of the ground. In a purely vertical descent that would be eliminated. In conclusion, he admired the courage of the author in attacking this very complicated problem.

Captain YEATMAN: Mr. McKinnon Wood had brought out the very points he himself had intended to make with regard to the constant angle of incidence. The only other point he wished to ask about was what happened to the propellers on the wing tips. It seemed that they must give rise to a gyroscopic force, and there must be a pitching moment on each blade which would vary periodically once in every revolution. As far as he could understand the machine, the blades of the helicogyre were not only articulated in the horizontal and vertical directions but were also articulated in pitch, the pitch being controlled by means of the ailerons. It was a matter of experience with autogyros that if the pitch changed—as had happened, as a matter of fact, quite suddenly, by accident—the blade flies right up and becomes practically out of control, and therefore he was interested to know what would happen to the author's machine when he got it into translational flight with the pitch controlled only by means of the flaps, assuming at the same time that the pitch was subject to fluctuating gyroscopic forces and various other complicated forces at the tip owing to the change of advancing speed of the propeller on the wing tip as it went round. Its régime was changing all the time, and unless something was done the engine revolutions would change, and there would be lag between speeding up and slowing down of the engine owing to the alteration of the advancing speed of the propeller as it went round with the wing. There seemed likely to be such a number of fluctuating forces applied to the wing tip that he would be surprised if trouble of one sort or another was not encountered. Another question was how the petrol was fed to the engine. Surely it would not be possible to use an ordinary float carburettor.

M. ISACCO: The ordinary carburettor worked all right. All that happened was that at the start there was a little excess petrol.

Captain YEATMAN: That is surprising. His only other point was that the author spoke in a rather optimistic way of getting a machine weighing 30 lbs. per h.p. He seemed to overlook the fact that in ascending vertically he had an engine in front, which had not up to then done any work, and he had to carry it about with him all the time.

Mr. RALLI: Referring to the movement round the wing tips, he concurred with previous speakers in the belief that, with limited articulation, torsional oscillations and hunting due to gyroscopic forces would occur; considerable expenditure of structure weight might be necessary to resist these forces. There

might also be disturbances due to the periodic variations in the velocity of advance of the wing tip airscrews. Possibly observations on these points had already been made in the course of the test flights mentioned by the lecturer.

As regards sustentation it was well known that it was possible to put sufficient power into a propeller to obtain adequate lifting force. This was essentially a question of pounds of aircraft weight per b.h.p., and of propeller diameter. Ordinary propulsive screws could only develop 3 to 5 pounds of thrust per b.h.p., but by increasing diameter to the sizes available on the helicogyre 15 lbs. per b.h.p. or more could be obtained theoretically. (This would allow a limiting all up aircraft weight of $15 \times 200 = 3{,}000$ lbs. for two 100 h.p. engines at the wing tips with a 40ft. diameter lifting screw). As a compromise more power could be allotted to the wing tip engines to make sustentation more positive. This additional power plant weight might have to be at the expense of speed or other qualities.

Positive sustentation was therefore possible, but would entail an increasingly cumbersome lifting system as the weight of the machine increased.

As regards forward speed of the machine it seemed that in addition to the usual parasite resistances the aerodynamic efficiency of the helicogyre must be seriously impaired by the disturbances due to the revolving power plants and structure; it was therefore difficult to visualise how the performance of this type of aircraft could even approximately rival that of orthodox aeroplanes.

Mr. A. G. Von Baumhauer (of the Amsterdam Research Laboratory): He would like to ask the author what were the difficulties that had been experienced with the helicogyre. Was there any evidence of vibration, and could details be given of the difficulties generally?

He could not quite appreciate the theory that had been developed with regard to horizontal flight. M. Isacco stated that the angle of incidence should be constant. He thought that in this case an endeavour should be made to have the lift at up-wind and down-wind sides almost equal. Thus the product, speed^2 $\times$ aerodynamic angle of incidence, should be constant.

He thought that this object could be better obtained by inclining the plane of rotation, the lifting screw giving the horizontal thrust.

As an illustration how tilting tends to symmetry, he pointed to the extreme case where the axis of rotation has got a horizontal position.

Finally he would like to know what would happen if one of the opposite engines gave less power than the other, a failure which might frequently happen. In that case there would be an eccentric force which might lead to disastrous oscillations.

Mr. F. Handley Page: Personally he was not yet persuaded that the helicogyre was going to replace the aeroplane. It was necessary to look at *all* the conditions to see what was best.

The principal advantage of the helicogyre was that it could rise vertically upwards, but he was not at all sure that that was an advantage. It was also claimed that it was possible to land in a small field, but there was the disadvantage that it was not always possible to get out of a small field again. The helicogyre was supposed to get out of a small field, presumably in the middle of a city surrounded by houses and by people who had no interest in aviation but a very considerable interest in seeing that their property and their lives were preserved. When a pilot on a helicogyre got out of the small field and was rising vertically he still had to maintain himself by reason of the engine, and if that engine "gave up the ghost" the machine would probably drop on top of one of the houses surrounding the small field. Therefore he felt that, until engines were more reliable, even with a multi-engine machine, the method of lifting a machine proposed by the author is one that would not be looked upon with favour by the inhabitants of thickly populated districts.

Even supposing, however, that vertical rising was required and that it was an advantage, the disadvantages of the system must be looked at. In the first place, the aerodynamic efficiency, as measured by the lift drag of the machine, must be worse as a whole when its planes went round and round in a circle instead of proceeding straight from point to point. The second disadvantage was that the propelling elements at the wing tips must be designed to meet a whole series of varying conditions which obtain in the complete circle of rotation of the supporting elements. On the other hand, the propeller of an aeroplane was designed for one and the most efficient condition, *viz.*, that of flying at cruising speed from point to point, and the only other consideration was to design the propeller with adequate thrust to take off. In the helicogyre, on the other hand, there were all the varying conditions from maximum forward speed to maximum reverse, and there was bound to be a much lower efficiency under these conditions.

There were also other points apart from the theoretical and aerodynamical side that seemed liable to lead to trouble from the practical point of view. The machine had wings fitted with Bristol Cherub engines and an Armstrong-Siddeley Genet engine in the front. He presumed there would be no quarrelling among the aircraft engine manufacturers, but apart from that, when the existence of four two-cylinder engines at the ends of the blades driving propellers was considered, even the best aero engines had been known to shed parts such as cylinders or plugs and other things at times. That was bad enough when the engine was fitted in a fixed fuselage and fixed wings, with which one could glide down to the aerodrome, even if it had to be a large field, and there was some prospect of doing it safely. When, however, one had these elements rotating round at the ends of large moving wings, it seemed to him there was always a very big risk of danger if anything happened to the engines. Again, there were known disadvantages accruing from the use of rotating engines in the old days of the Gnome and Rhone engine, and the very careful balance that had to be maintained of all the parts. It seemed to him that the same difficulty would arise when the engines were at the ends of the wing tips. Again, there was the question of the possible vibration of the propeller blades, and, taking it all round, aerodynamically and mechanically, he still felt there were a good many things to be said for the old aeroplane, even though it might require a large field to alight on and get off from. In the aeroplane, however, one had managed to reduce the moving parts down to one single spot, *viz.*, the engine, or more spots, of course, if there were several engines.

The simpler way of obtaining vertical flight had always seemed to him to be a case of a machine with a fairly wide speed range and a fairly low ground speed, and then if one wanted to go round and round in a circle—which might appeal to the Air Ministry!—and gradually get height, it seemed to him there was a less likelihood of troubles. With the type of machine to which he had referred, it would be possible to circle over a fairly small field and gain height, and, having achieved the necessary height over the populated district over which they were flying, it would be possible to proceed forward in the normal manner. In a similar way it would be possible to spiral down in a very close spiral, provided, of course, that one had a fairly slow flying machine. It was very similar to the idea of the helicogyre, except that one employed an ordinary aeroplane for flying in an ordinary manner.

Nevertheless, if one disagreed with the author of the paper as to the particular type of machine, one must admire the genius that he had shown, and the perseverance displayed in developing the design. At the same time, one had only to read back a matter of 20 years to see the rude remarks that were made by ignorant people with regard to the aeroplane, and how it was

said that it could never possibly be of any use. Therefore, he rather felt at the back of his mind that in the future he might be in the same category as those people who once jeered at the aeroplane. Therefore, having said everything he possibly could against the helicogyre, he did so with a note of caution, and hoped that in the future he would prove to be right; but at the same time, not feeling quite sure!

Mr. MANNING: As the various previous speakers had dealt with all the points he had wished to raise, he would like to emphasise one aspect with regard to commercial aviation. The advantages of the aeroplane lay solely in its speed. It had no advantage except speed, either over such a scheme as that of the author or even over the motor car. With regard to military aviation, he did not think it was possible for any country to put up with a slower machine; indeed, if anything, machines for this purpose must be faster, and although a slower machine might have advantages as regards vertical lift he felt that before a machine of the type described by the author could come into general use it must compete with the present performance of the aeroplane as regards speed. The machine the author was building was fitted with four 32 h.p. engine, plus a 100 h.p. engine, a total of 228 h.p. An ordinary aeroplane with that engine power would be expected to have a speed of 140 miles an hour, and possibly more. Would the author say what he expected the forward speed of his machine would be?

Flight Lieut. BONHAM CARTER: It seemed to him that the author's machine, once it got into the air, was in a very similar position to that of the ordinary autogyro. The front engine would be working, and the others merely idling round. From that point of view, so much waste weight was being carried. Would the author say something about the arrangement of the controls from the pilot's point of view, and what he expected the pilot to do?

Mr. BROOKS SAYERS: He constructed a model moving wing machine some years ago, but he was not going to speak of that; the point he wished to make was that it would be better to use electric motors on the wing tips, if this method was really advantageous. That, of course, was a question of weight. There was a new light-weight type of dynamo of his invention, and some of which he had made for the Air Ministry for use on aeroplanes. As electric motors they could be run up to 10,000, 15,000, or 20,000, or still higher. Two armatures using one field could drive, through reduction gear, two propellers in tandem on each wing. If the motors were series wound and those on the several wings were coupled in series, they would accommodate one another. Those encountering greater resistance—moving against the motion of translation—slowing down, and those receding—as regards the motion of translation—speeding up; thus adjusting themselves to the speed variation as the wings revolved.

As regards weight, there would be a large saving per contra in eliminating petrol and oil tanks, starting devices, etc., from the wings, and having all power tanks, etc., concentrated in the fuselage. The motor controls would be extremely simple and absolutely reliable, while all would be accessible to pilot.

He had many years ago tested one of the first Delaval steam turbines running at 30,000 revs. per minute and driving a dynamo at 3,000 r.p.m. through 10 to 1 reduction gear. Marine engineers also,—many years ago,—stood aghast at the suggestion of geared turbines, but to-day they were commonly employed. The weight efficiency of very high-speed electric motors geared to suit requirements of power consuming element, such as a propeller, had yet to be ascertained and demonstrated.

He believed that such an arrangement was far more likely to be realised than the air jets suggested by the author at the end of the paper.

Major KENNEDY: As his name had been mentioned by the President he would like to record one or two points in connection with the history of this matter. He happened to be associated with some business men in London about three years ago, and through them first had the pleasure of meeting Signor Isacco. At that time the work of la Cierva was not common knowledge here. He (the speaker) personally had taken some part in introducing the Isacco helicogyre to the Air Ministry. A point that had not been mentioned during the discussion was that three years ago, and for some years previously, the British Government had had on offer to all and sundry the very substantial prize of £50,000 for anyone who could produce a helicopter to do certain prescribed things. The gentleman with whom he had been associated put forward Signor Isacco as a very promising candidate for that £50,000 prize. He did not know which was cause and which was effect, but shortly after that and before any formal entry could be made by Signor Isacco, that prize was withdrawn! It was only when he had the pleasure of meeting the author during the previous week that he had another opportunity of seeing how he had persevered and how he had achieved what seemed almost to be the impossible, in that alone and unaided he had succeeded in getting very valuable contracts from the French and British Governments simultaneously. That was a very great achievement, and must be appreciated at its proper worth. The only other thing he would say was that when the machine was completed at Cowes and Signor Isacco essayed his flight in it, he sincerely hoped that the four little Cherubs would carry him safely aloft.

Mr. BRAMSON: A little while ago he had the advantage of being able to ask some questions of M. Cierva about the autogyro, and particularly mentioned one trouble, *viz.*, what happened when the speed of translation was so great that the velocity of the wing going in the opposite direction to that of translation became nil in space, and therefore the lift became nil. The answer was that what actually happened was that the flapping inertia of the wing came into play and caused that wing—which ordinarily might give no lift—in point of fact to add to the lifting forces at that moment exercised by the wing. If the flapping inertia of the wings had an effect, beneficial or otherwise, that effect must surely be multiplied to a considerable extent if there were engines in the wing tips. Personally he could not claim to understand the question of the exact effect of that flapping inertia, and would very much like to be enlightened upon it. In effect, the machine that had been described was an auto-gyro, with the added advantage that it could rise without having to run for half-an-hour round a field, and could also be brought to earth in a more or less similar manner. There appeared to have been a large amount of mechanical difficulty associated with the design of a gear for the autogyro, which would do more or less the same thing but with the added simplicity that, instead of having three or four or five engines, only one or two were needed. Would not the idea of the author in hinging each blade individually round a vertical axis in addition to hinging round a horizontal axis enable a sufficiently strong combination of parts at the wing root to permit of gearing. It also seemed difficult to imagine that the problem of designing a gearing between the engine and the revolving wing should be utterly beyond the ingenuity of man. Finally, might he express the hope that, if Mr. Wimperis' enunciation of the principle that inventors should also be the first pilots of their machines implied reliance upon the law of survival of the fittest, the author would prove very fit indeed.

Sir A. V. ROE (*contributed*): According to a Press statement it was stated he was of the opinion that the Isacco machine had entirely solved the problem of vertical flight. He would like to point out that this statement did not come from him. He certainly thought the Isacco machine would provide very useful data towards solving the problem which he felt confident would be solved in the near future.

No doubt uses will be found from time to time for machines capable of lifting loads vertically, such as transporting mining machinery in mountainous districts, etc.

Mr. Handley Page seemed to be under the impression that engine failure would mean a certain crash, but it appears that such a machine could be under control and landed very gently with the engines stopped.

Personally, he would a thousand times sooner see money spent in experimental work of this nature than on the dole; no doubt useful information would be obtained by spending a small proportion of the available money for experimental purposes in this direction.

Reply to Discussion

Mr. J. L. Hodgson's general views on the possibility of the helicopter flight are in contradiction with the practical flight already achieved in various countries with different helicopter machines.

Brennan, in England, has achieved vertical flights without any difficulty. These flights might have been attained at a greater height if the machine had been provided with all the elements of safety. Mr. Wimperis' authorised opinion on this machine is that the lack of any articulation on the wings accounted principally for the cause of the failure.

Oemichen and Pescara in France have performed the best flights in this country. One mile in translation, 10 to 12 feet of height and 10 to 12 min. of flight, were the best performances achieved. An analysis of the reasons for the relative failure of these machines show clearly that it was due to defects of the principles adopted, of which the most essential were a highly complicated and unsafe mechanical system and a lack of stability whilst the machines were hovering.

Petroczy-Karman in Austria have succeeded in making a remarkable vertical flight to a height of 150 feet. This machine was not provided with any automatic or controlled stability and broke down because of the failure of the mechanical transmission.

Berliner, de Bothezat, etc., have also performed some interesting flights.

All of these flights have not been kept secret, and I do not understand why Mr. Hodgson bases his judgment upon his laboratory results only, however interesting the same may be. I am not in a position to control the methods adopted for these tests, but I am of opinion that mistakes can easily be made with small models running in water, instead of models of a much larger diameter running in a strong current of air.

To conclude I should like to point out to Mr. Hodgson that the relative failure of the previous vertical-flying machines is not due to the heavy weight in horse power of the engines, but solely to the failure of the principles adopted. It is much harder to find these principles than may commonly appear, and the experience afforded by the previous attempts was necessary to bring about a solution on a practical basis of vertical-flying machines, the performances of which are obviously bound to improve when lighter engines shall be found and made use of.

Mr. Hodgson's suggestion that the wings should be rigid is in contradiction with the evidence, since the articulated wings provide, as has been proved in practice, for an inherent stability of the machine and allow also of much lighter wings. Why then complicate a difficult problem by devices which it is much harder to resolve practically than it appears?

I thank Mr. McKinnon Wood for his remarks, which enable me to enlighten certain points which were not completely set out in the lecture.

In the comparison made of the helicogyre and the helicopter flights, the blades were considered rigid. With hinged blades the flapping will vary the incidence of the blades, but the value of the comparison is not altered. This flapping in the helicogyres is much less in amplitude than that of the autogyros, owing to the weight of the engines, petrol and oil tanks, etc., which are fitted on the tips of these blades. Therefore, the influence of this flapping on our machines will be much less important than on the autogyros. That is the reason why in my comparison I thought it was of no theoretical interest to include the flapping.

I disagree with Mr. Wood's opinion that the flapping up and down of the wings is the reason why the rolling moment is rendered nil, when the machine is in translation. The flapping has the effect of decreasing the incidence of the blades when they are subject to a high relative speed of air flow and of increasing this incidence when this speed is low. Therefore the flapping decreases the rolling moment but it does not render it nil. The reason why the machine does not overturn is really due to the fact that the blades being articulated they give way under the pressure of the air flow and cannot in this way transmit an appreciable rolling moment to the body of the machine. As an example I ask Mr. Wood to analyse an autogyro in a practical vertical descent when no appreciable flapping due to translation occurs and no lateral stability is available to the pilot. In this descent the machine does not and will not turn over under lateral gusts of wind.

I will give another theoretical example which may help in understanding the real effect of the articulated blades.

Consider a set of wings (Fig. 1) in horizontal translation at a speed (V)—equal to the average speed of rotation ($w\rho$) of these wings. With rigidly fixed wings (Fig. 2) the pressure will be nil when the blade is in position (B) and very important—$F = k\,(V + w\rho)^2$ when in position A.

The rolling moment will be equal to ($F \times \rho$), (F) being in this case equal to the total weight of the machine and (ρ) being the distance of the centre of pressure to the central axis.

With hinged blades the pressure (F) will be balanced by the vertical component to the blade of the centrifugal force (F_2C_2) increased by the weight (p) of this blade.

Practically the only forces remaining are the radial components (F_1C_1) which (especially in helicogyres where a is very small) are scarcely different. The resultant (R) will give a vertical component (Q) equal to the weight of the body of the machine, and an horizontal component (h) which only gives way to a rolling moment equal to $h \times d$, (d) being the distance from the axis of the blades to the centre of gravity of the machine.

This rolling moment is very, very small, and many times smaller than the previous overturning couple found with rigid blades. The energy of the overpressure is absorbed by the work necessitated by the lifting of the blades, or, in other words, by the work necessary to overcome the resistance due to the component (F2 C2) of the centrifugal force. The residual rolling moment, if not corrected by any of the means at the disposal of the pilot, will produce a slight lateral inclination of the machine.

With reference to the inflow or to the induced velocity, I ask Mr. Wood to note that this inflow is very important while the machine is hovering, and therefore affects in this case the incidence of the blades, but it may be neglected because it is very small when the machine is in horizontal translation. The

case is the same with aeroplanes where the inflow, which exists as well, is neglected, although it is known that it slightly decreases the incidence of construction of the wings. In helicogyres, whilst hovering or in vertical ascent, the incidence of the blades is considerably increased by means of the ailerons controlled by the pilot, so as to compensate the influence of this inflow.

The objection that I am a little optimistic in the comparison between helicogyres and aeroplanes does not surprise me. It is true that the design of an aeroplane will remain the cleanest of all. With helicogyres, in which the wing-engines will be in the inside of these wings, the only supplementary resistance will be the central hub and pylon. I hope, however, that in the near

Fig. 1.

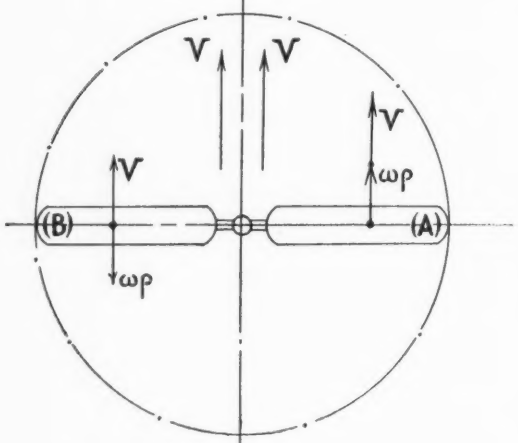
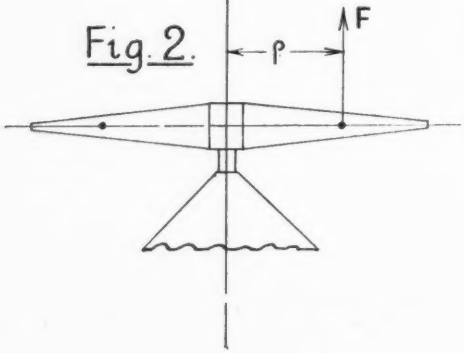
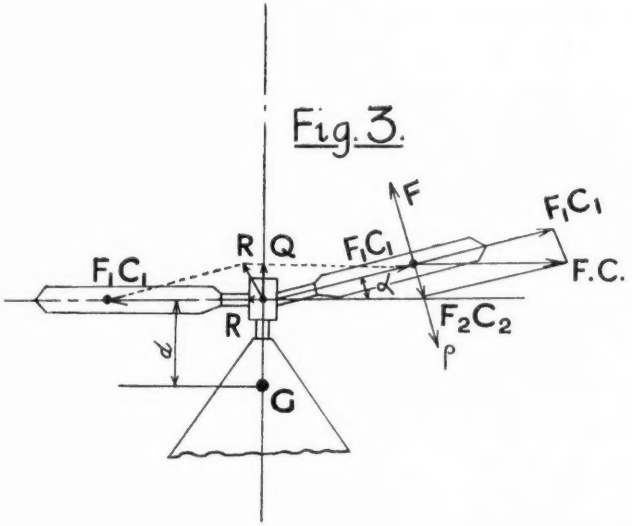


Fig. 2.





future the landing carriage will be suppressed, and also that the wings, subject only to a constant fatigue, will be thinner than the corresponding wings of aeroplanes. Therefore I expect that I shall at least be in as good a position as the aeroplane.

As to the rate of climbing it is a mistake to believe that helicogyres will not climb as fast as aeroplanes. In an oblique ascent the quality of climb of helicogyres will be superior to that of an ordinary aeroplane, and that owing to the lift produced by the wing-engines.

Captain Yeatman's queries give me an opportunity of discussing briefly some points which could not be developed in the lecture. The gyroscopic force produced by the propellers driven by the wing-engines will vary periodically if these propellers are twin-bladed. But with a four-bladed propeller this gyroscopic force is constant and tends either to increase or to decrease the pitch of the blades. In my machine No. 1 each wing-engine controlled two four-blade propellers turning in opposite directions, a reverse gear being fitted in between them. There consequently was no appreciable gyroscopic force acting upon the blades. In machine No. 2 each wing-engine drives a single four-blade propeller, and the corresponding gyroscopic reactions are equilibrated by means of aerodynamical devices which give much better practical results.

Referring to the accident which happened to autogyros where the blades fly right up when the pitch was accidentally changed, I have experienced a similar accident in our early trials. The matter is very satisfactorily overcome at present by means of a very simple aerodynamical device which maintains the blades at the constant angle of flight desired by the pilot. In translation the same device operates in the right way so as to decrease the pitching of the blades when the relative speed of air flow is the greatest, and *vice-versa*.

Referring to the change of speed of the propellers driven by the wing-engines whilst the machine is in translation, simple devices have been embodied in my machines in order to overcome the drawbacks as stated. I hope, in the near future, to have an opportunity of completely developing the theory of the work of these propellers in translation and the means adopted to maintain an

almost constant speed of the engine's revolutions. In conclusion to Captain Yeatman's queries, I may say that these troubles have been experienced and corrected by means of simple and automatic devices.

Referring to the weight lifted per horse-power, I should like to point out that in vertical ascent where the efficiency of the machine is the worst, I expect to lift up to 30 lbs. per horse-power. If the front engine is utilised that means if the machine runs along the ground as with the ordinary aeroplane, although for a much shorter distance, the lifting capacity will obviously increase, and the figure of 30 lbs. per horse-power will be correct, including the h.p. of the front engine.

I must insist upon the fact that the function of helicogyres is double. They can fly like helicopter machines and like aeroplanes; therefore the comparison on the total horse-power provided to the machine is not easily to be made.

Mr. Ralli thinks that an increased structure-weight might be necessary to the variations of the gyroscopic forces as well as to limitate the oscillations and the variation of pitching of the blades. Not a single mechanical device is required for that purpose, the only aerodynamical device mentioned above being entirely sufficient. The parasitic resistances of the revolving engines and structure, if they exist in my experimental machines, will be wholly suppressed in future helicogyres. The engines will be fitted in the inside of the wings, not a single cable or lever of control will be outside of the wings, and as also the landing carriage will be transformed or suppressed, the total resistance to translation of the machine will be at least as low as that of an ordinary aeroplane, and as a consequence thereof the performances will be approximately equal.

In answer to Mr. A. G. Von Baumhauer's queries, numberless difficulties had to be overcome before performing the vertical lifts mentioned in the lecture. The variation of incidence of the blades and their elastic support and arming to the central column and hub were very intricate.

The reverse gear fitted in the machine No. 1 between the two propellers turning in opposite directions gave many worries. The regular control of the carburettor levers was not an easy matter, and a device to control separately and simultaneously all the wing-engines had to be embodied.

As to the vibrations they are of no consequence at all.

I repeat that in translation the incidence of the various elements of the blades, when these are in the different positions during one revolution, should be as near as possible to the angle of the best lift to drag. Then the efficiency of the machine could be compared with that of an aeroplane in which all the elements of the wings work at the best angle of incidence.

In the helicogyre flight with rigid wings this angle is constant. This angle varies slightly from this value when the wings are articulated. In the autogyro flight the incidence of the different elements vary also continuously, but their average value is very nearly the same as that of an aeroplane flying at a steady angle. In the helicopter flight with the axis of the machine inclined forwards, the incidence of the different elements varies so much along the blades and for every position of these blades in space that the average value of the lift to drag is much worse than that of other systems of flight.

On the other hand it is impossible to obtain, with an acceptable efficiency, an equal lift at up-wind and down-wind sides. If the wings are articulated this is not necessary, and if they are not then a second sustaining set of wings turning in opposite directions becomes necessary. The fitting of a mechanical device to correct the rolling moment (if the wings are rigid) is a very complicated, practical thing, and dangerous, because of the continuous gyroscopic reactions of the sustaining wings which would easily overturn the machine.

In answer to the last query—if one of the opposite engines gives less power than the other—the eccentric force will give way to slight oscillations, which, as was proved practically, are not at all dangerous.

Mr. Handley Page's opinion that helicogyres or any other vertical flying machines, even if they afford a practical means of flight, might be a danger for populated districts, looks very much like the objection raised to motor-cars when they were first started. Everyone knows the extraordinary development of this mode of motion during the last 20 years. Vertical flying machines will always find a place to land, while large landing grounds are required for aeroplanes.

Referring to the efficiency of helicogyres I have agreed, because my theoretical calculations showed it, that the aerodynamical efficiency is slightly less (in no case more than 7 per cent.) than that of the corresponding aeroplane. But I am inclined to rely on La Cierva's arguments that for certain small angles of incidence the ratio of lift to drag might be at least as good as that of an aeroplane. A further advantage of helicogyres is that the incidence of the wings being variable they can be adapted to the different heights of flight, and it is known that this would represent also a considerable advantage to aeroplanes if such a device could be easily embodied in the latter.

It is correct that the propellers driven by the wing-engines have to meet different requirements, and therefore that their average efficiency is less than the ordinary front propeller of an aeroplane. As this question is thoroughly studied I may say that it appears already possible to obtain a very good efficiency with the wing-engines running faster than the present available engines and with an appropriate section of these propellers which will be convenient to the variation of the relative air flow.

Referring to the objection that it might become dangerous for the machine if cylinders are lost by one of the engines during flights, practical trials with different weights on the blades have shown that it will entail only slight oscillations to the machine, in no case dangerous. The loss of some plugs will not affect the machine at all, and as for cylinders, when the engines are fitted in the inside of these wings, there is no reason why the broken cylinders will not stay there.

One of the La Cierva's autogyros once lost one of its wings in flight, and a disaster which would have been fatal for an aeroplane was nothing but a minor accident.

I cannot understand the comparison of my wing-engines with the rotary Gnome and Rhone engines. My engines are not rotary. They work exactly like ordinary fixed engines, with the difference that they run also around a circle.

Mr. Manning's opinion that only speed is required both for commercial and military aviation does not seem to me to be correct. For certain special purposes speed is, of course, indispensable, but for the majority of the cases safety and economy are required in the first place. Machines capable of landing and starting from the decks of ships will find numerous applications which are not possible for aeroplanes. The doing away with of large and costly landing fields and their substitution by more numerous landing places close or in the centre of towns, will give to aviation a development which will surpass all other known means of transport. Finally, the safety felt by the passengers for landing in case of stopping of all the engines will induce people to adopt this quick way of travelling. Everyone knows that this is not the case with the present aeroplanes.

On the other hand helicogyres will go as fast as aeroplanes, and if a little more horse-power is required the economy afforded by the above-mentioned advantages and the profits made by a much more extensive exploitation will

more than cover the cost of a few more gallons of petrol. In pure helicogyre flights the necessary total horse-power as compared with aeroplanes will be approximately 10 per cent. in excess and a little more than that in helicopter flights. But what can be done in transport and industry by a helicopter machine will never be achieved by aeroplanes.

My present machine is an experimental one and I do not expect more than 80 to 90 miles an hour, but I must say to Mr. Manning that at that speed a maximum of 50 per cent. of the power of the wing engines will be used. The same machine adapted to helicogyre flight with the same total horse-power (four engines of 15 h.p. in the wings and one of 168 h.p. on the fuselage) will fly approximately at 110 to 120 miles an hour and there is no doubt that this figure will be improved as in the light of future experience.

Flight Lieutenant Bonham Carter's opinion that once in translation, helicogyres will be in a similar position as an autogyro is not correct. There is a fundamental difference between autogyros and helicogyres. In the former the power required to run the windmill in translation, is given by the front engine, or in other words, all the necessary power required to overcome the resistance of the machine in translation and the sustentation is provided by the front engine. In the latter the power absorbed by the windmill during its rotation is assured by the small engines fitted on its blades. The front engine will only have to overcome the resistance to translation of the machine. In short, I may say approximately, that in helicogyre flights (as described in the lecture) the horse-power provided on the wings added to the horse-power of the front engine will be equal to the h.p. of the single engine in a corresponding autogyro.

A consequence of this division of the power is that the windmill can run without the necessity of a previous translation. In vertical descent the use of the wing engines will also decrease considerably the rate of descent.

Referring to the pilot's controls, I have arranged the main ones exactly in the same way as in an ordinary aeroplane. The rudder, the elevator and the lateral stability are identically controlled. The ailerons, instead of being fixed, as they are in autogyros and aeroplanes, are in my machines rotating with the wings. These ailerons are also controlled longitudinally at the same time as the elevator, so that in translation they work simultaneously and in vertical flight the ailerons only are useful. Two supplementary levers are fitted in my machines, but these are utilised only when a change of the path of flight is required (planing, vertical ascents and descents, etc.). One is a lateral lever for the control of the main ailerons of the wings and therefore for the regulation of their incidence. The second is a lateral hand-lever for the simultaneous control of the throttles of all the wing engines.

In answer to Mr. Brooks Sayer's query, I believe that it will be possible for certain special purposes (mining works, etc.) to utilise electric motors on the wings, provided, of course, that these motors do not exceed a weight of 5 lbs. per h.p. The only trouble is that the gear reduction will be required, though in this case the problem can be practically solved.

For long range flights and until very, very light electric batteries are discovered, the question of the use of electric motors cannot be considered, and even in that case their use will give much less advantages than direct jet propulsion engines which, in my opinion, will represent the best system of running vertical flying machines.

I refer Mr. Bramson to my answer to Mr. Wood about the effect of the flapping of the wings. Regarding the possibility of driving the windmill by means of a mechanical gear transmission, my work on numerous machines, based on such a system, has proved to me that it is extremely difficult to achieve this practically and, even if achieved, it will considerably increase the weight of the machine and render it always delicate and therefore probably unfit for commercial and private purposes.

Extract from a Paper entitled:

TESTS ON MODEL PROPELLERS

BY

JOHN L. HODGSON, B.Sc., Assoc.M.Inst.C.E.,

which was read before the Institution of Automobile Engineers in March, 1917

I.—The "Characteristic Curves" of a Propeller

In 1915, when dealing with various problems connected with Lifting Screws, the author desired to obtain a general idea as to the performance of a propeller when it was moved at various speeds forwards and backwards[1] along its axis of rotation, and to express this information in some simple way, so that the approximate performance of any similar propeller working in a fluid medium of any density might readily be deduced.

If, when comparing the performance of similar propellers working at the same slip ratio, the resistances due to skin friction and viscosity are assumed to follow the velocity squared law, and change of density in the neighbourhood of the propeller is neglected, there are six main factors to be considered. These may be taken as:—

Thrust in lb.	T
Revolutions per minute	N
Torque in lb.-in.	q
Speed of advance in feet per second	V
Density of fluid in which propeller rotates, in lb. per cubic foot	W
Diameter of propeller in inches	d

For given values of W and D it is not possible to predict accurately by any simple theory the manner in which T N and q will vary for different values of V. This may, however, be determined experimentally, and expressed by means of curves. The experimental values may be obtained in three ways, *i.e.*, with T constant or with N constant or with q constant. In the experiments described in this paper the first way has been adopted.

If, instead of plotting the experimental values of N and q obtained at various speeds of advance for given values of W and D when T is constant, we plot non-dimensional coefficients which connect these values with two or more of the other variables; general curves are obtained from which the performance of any similar propeller under any conditions may be deduced. Such curves, which are plotted at (1) and (2), Fig. 6, may be termed "the characteristic curves of the propeller," since they entirely define its performance under any given conditions.

If the units in which the six variables are measured are consistent among themselves, these "characteristic curves" can be used without recalculation for any consistent system of units.

The "characteristic curves" given in the present paper cannot be so used, as, owing to the short time available for the preparation of this paper, it was found necessary to give the results in terms of the units actually worked with.

The propeller (see Fig. 1), on the tests of which the curves given in this paper are based, was 6.25in. diameter and approximately 6in. pitch. Its blades,

[1] As far as the author could discover, no tests at negative speeds of advance had previously been made.

and those of the propellers described in the following paper, were constructed of soft brass, and were attached to a central boss.

These were first machined up in the form of rings of the required blade section, which were sawn through and flattened out so as to form strips. These strips were then cut to the required blade outline, and shaped to the desired pitch on helical forming blocks by means of burnishers. Any desired modification of the blade section towards the tip or the root of the blade was made before the final burnishing, so that the pressure face of the blade was always truly helical in shape.

All the tests on these propellers were carried out in water.

The method outlined above enabled a model propeller having two or more blades to be accurately constructed in a few hours; while the method of testing in water greatly reduced the speed of rotation required to produce a given thrust, and by enabling the blades of the propeller to be constructed of metal, obviated the possibility of any appreciable amount of deformation under load.

A sketch of the experimental apparatus used is shown in Fig. 2, and a photograph of the actual apparatus in Fig. 2A, Plate XIV. On reference to

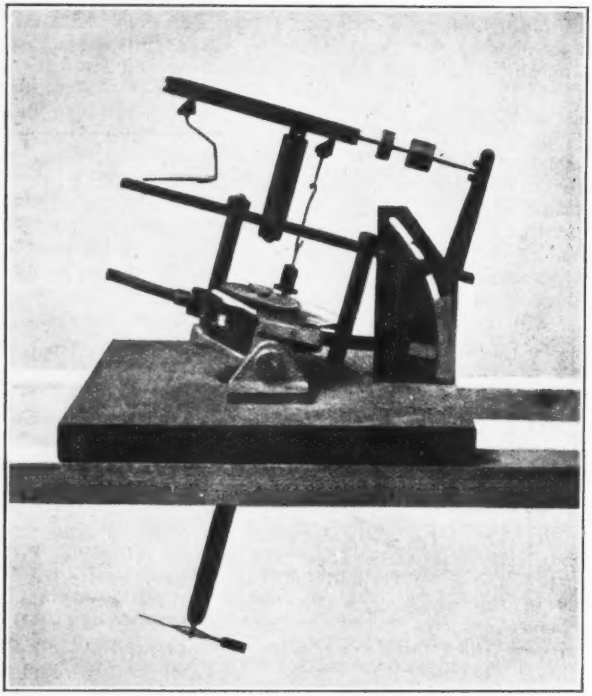


FIG. 2A.

this Figure, it will be seen that the propellers were attached to a vertical spindle which was fixed in the centre of a bell-mouth which formed the outlet of a vertical pipe 12in. in diameter. Through this pipe water could be passed at various velocities up to 5ft. per second. The volume flow was measured by means of a Venturi Tube V T, Fig. 3, which was placed upstream of the bell-mouth, B, while the approximate mean velocity across the central area in

which the propeller worked was deduced from Pitot Tube readings taken through a hole in the side of the bell-mouth at given volume flows with the propeller removed.

The plane of the propeller was about 11in. below the overflow level of the bell-mouth, a series of tests having shown that the relations between T, q, N and V became constant before this depth was reached.

The vertical spindle to which the propeller was fixed was rotated by means of a small air turbine, the torque due to which was obtained from the readings of a manometer, which measured the pressure at the driving jet, the relation between the torque and the manometer reading having been previously determined by brake tests. These brake tests were taken at various turbine speeds, so that the delivered torque at any speed was known independently of the windage of the turbine.

The torque readings were checked at the beginning and at the end of each day's experiments by substituting a square-bladed fan for the propeller and observing that the speed corresponding to any given manometer reading remained constant.

The propeller spindle was provided at its upper and lower ends with ball-bearings, which were so designed as to allow free end motion.

The push or pull on the spindle was measured by means of a delicate balance, one arm of which was attached by a flexible connection to a self-aligning ball bearing thrust-washer mounted at the top of the spindle.

The speed of rotation of the spindle was measured by timing the revolutions of a slow-running wheel geared to the propeller spindle.

The water was always passed through the bell-mouth in the same direction, but by reversing the propeller on its spindle and its direction of rotation, the propeller could be made to advance into the stream or to recede through it.

To enable the direction of rotation to be reversed, two tangential nozzles were provided, the jets from which were capable of rotating the turbine in opposite directions. One or other of these was used according to the direction of rotation desired.

The blades of the turbine were flat, and were fixed radially, and parallel to the axis of rotation. By this means end thrust due to the impact of the jet was avoided, and the turbine worked under similar conditions for both directions of rotation.

The sides of the turbine casing were left open, and its ends were made similar, and were placed at some distance apart, and at equal distances away from the turbine wheel; so that the suction due to the turbine acting as a centrifugal fan did not affect the measured thrust.

In order to avoid errors in the measurement of the thrust due to slight friction in the bearings of the vertical spindle, the scale beam was adjusted to read zero thrust when the turbine was rotating with a weight equal to the weight of the propeller to be tested (and of the same material) temporarily attached under water at the lower end of the rotating shaft.

The thrusts measured during these experiments varied from 0.08 to 0.32 lb., and the apparatus when running was sensitive to a variation of thrust of less than 0.0005 lb.

In order to compensate for the increase of buoyancy of the vertical spindle due to the rise in the overflow level of the bell-mouth at the higher speeds of advance, riders corresponding to the particular speed of advance were placed on the scale beam.

It will be obvious that the error due to the proximity of the walls of the bell-mouth is of most importance when the speed of advance is zero. Permanent currents are then set up by which water which has been discharged from the propeller is caused to circulate, and again to pass through it. Further, the water in the bell-mouth is set in rotation, and this rotation goes on increasing

until all the rotational energy given to the water by the propeller is dissipated in friction at the walls of the bell-mouth.

When, however, the speed of advance is increased from zero, these currents tend to be swept away, and the error due to the proximity of the walls of the bell-mouth gradually become of less importance.

A series of comparative tests taken in the same bell-mouth with similar propellers, 3in. and 6.25in. diameter respectively, showed that at comparatively small positive or negative speeds of advance the proximity of the walls of the bell-mouth produced practically no effect. These tests show that model propellers may be accurately tested in wind tunnels.[2]

In the curves for the 6.25in. diameter propeller plotted in Figs. 4 and 5, the points at zero speed of advance are plotted from observations taken in an open tank 20ft. square. It will be seen that these points join up very well with the points taken at speeds of advance corresponding to 6in. per second.

For the points taken at zero speed of advance in the bell-mouth the torque was found to be about 10 per cent. less, and the revolutions about 10 per cent. higher than for the same points taken in an open tank.

As previously stated, the torque and revolutions were measured at constant thrust for various speeds of advance; so that a convenient way of recording the tests was to plot curves of equal thrust which related the observed torques and revolutions and speed of advance.

The experimental results reduced to 1 lb. thrust for the 6.25in. diameter propeller are plotted in Figs. 4 and 5 previously referred to.

This reduction[3] was effected by multiplying the observed values of N by $1/\sqrt{T}$, and the observed torques by $1/T$, where T is the observed thrust.

The revolutions and torque for zero thrust are also shown.

A few special points of interest which are brought out in these curves may be noted:—

(1) The dotted portion in the V, N curve in Fig. 4 indicates that for this part of the curve the speed, and also the direction of rotation, are unstable with the apparatus employed.

If the apparatus had been designed in such a way that the speed could be automatically maintained constant while the torque and thrust were measured, this part of the curve could have been determined; as could also the corresponding part of the V, q curve (Fig. 5).

(2) On considering such pairs of points as AA′, BB′ and CC′, it will be seen that when the speed of advance is negative it is possible to obtain the same thrust at different torques and with the propeller rotating at widely different speeds.

(3) It will be noticed that the experimental mean pitch, as determined from the lines of zero thrust,[4] is greater when the fluid impinges upon the leading edge of the propeller than it is when the propeller is reversed and the fluid impinges upon the trailing edge. In the particular case illustrated in Fig. 4, the experimental mean pitch changes from 6.55in. to 5.06in. when the speed of advance becomes negative. As is well known, the experimental mean pitch corresponds to the angle of attack which gives zero thrust for the aerofoil section for which the propeller is designed. It will, therefore, be obvious that since the angles of attack for the zero thrust for forward and backward motions of the aerofoil section are inclined in opposite directions to its chord, there must be a wide difference between the experimental mean pitches for positive and negative directions of advance.

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[2] As propellers are now (1929) usually tested in wind tunnels, this conclusion was of considerable importance.

[3] It will be noticed that the points so reduced lie fairly well together, thus justifying, over a range of thrust of one to four, the approximate assumptions made in deriving equations (1) and (2) below.

[4] At zero thrust, the experimental mean pitch multiplied by the revolutions equals the speed of advance.

Since the experimental mean pitch corresponds to the direction of the zero thrust of the aerofoil section, it is of much more value than the pitch of the chord of the aerofoil section (*i.e.*, the true or designed pitch) when comparing the performances of different propellers at various slip ratios. It should, however, be noted that the experimental mean pitch as measured is always slightly less than the pitch corresponding to the no thrust line for the blades alone, owing to the resistance of the central boss of the propeller.

In using the results which are plotted in Figs. 4 and 5 to deduce the performance of similar propellers of any size working in a fluid medium of density, the various factors to be co-ordinated are N, q, V, T, W and D.

The tests plotted in Figs. 4 and 5 show how N and q are related to V when T, W and D are constant. The variations of N, q and V with T, W and D follow quite simple laws[5] for points on the curves for which the ratio V/D N (a term corresponding to the "slip ratio," and defining a kind of average "angle of attack" for the whole blade) is constant.

We may therefore determine coefficients α, β and γ, which connect N, q and V with expressions involving T, W and D.

This is done as follows:—

Since $T \propto N^2WD^4$* for points for which the ratio V/DN is constant, we may write

$$N = \alpha\sqrt{\frac{T}{WD^4}}$$

whence

$$\alpha = N\sqrt{\frac{WD^4}{T}} \quad . \quad . \quad . \quad . \quad (1)$$

Also, since

$$q \propto N^2WD^5$$

$$\propto \alpha^2\frac{T}{WD^4}WD^5 \text{ by (1)}$$

we may write

$$q = \beta TD$$

whence

$$\beta = \frac{q}{TD} \quad . \quad . \quad . \quad . \quad (2)$$

Further, since for the points considered the ratio V/DN is to be constant, we may write

$$V \propto DN$$

$$\propto D\alpha\sqrt{\frac{WD^4}{T}} \quad \text{by (1)}$$

$$= \gamma\sqrt{\frac{T}{WD^2}}$$

whence

$$\gamma = V\sqrt{\frac{WD^2}{T}} \quad . \quad . \quad . \quad . \quad (3)$$

In the above, α, β and γ are numerical coefficients which may be calculated from the experimental results.

Curves connecting α and γ, and β and γ, are plotted at (1) and (2), Fig. 6. These curves, if used in conjunction with equations (1), (2) and (3), enable us, if we know T, W. and D, and one of the variables N, q and V, to find either of the other two.

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[5] If it is assumed that the forces are proportional to areas, densities and squares of velocities. It should be noted that these assumptions are only approximately true. (See Appendix I.)

Of the possible problems which may arise in calculating propellers which are geometrically similar to the model used, the following cases can be solved by means of equations (1), (2) and (3), and the curves given at (1) and (2), Fig. 6.

CASE I.—To find N and q when T, V, W and D are known, calculate γ by equation (3).

Read the corresponding values of α and β from the curves.

Calculate N and q by equations (1) and (2).

CASE II.—To find q and V, when T, N, W and D are known, calculate α by equation (1).

Read the corresponding values of β and γ from the curves.

Calculate q and V by equations (2) and (3).

CASE III.—To find N and V, when T, q, W and D are known, calculate β by equation (2).

Read the corresponding values of α and γ from the curves.

Calculate N and V by equations (1) and (3).

In general, given any four of the six variables, the remaining two can be determined. There are fifteen possible combinations[6] of known and unknown variables, including the three cases dealt with above.

To enable any of the remaining cases to be readily solved, it will be found most convenient to derive a number of additional equations and curves from the three equations and the two curves already discussed. The method of doing this is best explained by taking one of these other cases as an example.

Thus, let us take the case when N and T are the unknown variables. This is listed as Case IV. in the accompanying Table. By combining β and γ in the manner indicated in column 3 of Table I. (γ^2/β), we get the function WD^3V^2/q, which, it will be observed, does not involve either of the unknown variables, N and T, and which can be evaluated directly from the data given.

By reading off a series of points from the original curves, we can tabulate corresponding values of α, β and γ. For each of these points we can calculate the value of $(f)_4$,[7] *i.e.*, WD^3V^2/q or γ^2/β, and from the values thus obtained draw the curve connecting $(f)_4$ and γ.

Referring to Table I., column 2 gives a list of possible combinations of unknowns.

Column 4 gives functions derived from α, β and γ, which in each case do not involve either of the unknowns in column 2, and which for convenience of reference are designated as in column 5.

Column 3 shows how these functions are derived.

If we now read and tabulate a series of values from the two curves relating α and γ, and β and γ,[8] we can calculate a corresponding series of values for each of the functions in column 4. We next plot[9] each of these functions against γ (see Figs. 6 and 7), so that if we know the value of one function, we can read off from the curves the value of any other required.

Thus, when N and T are unknown (Case IV. in Table I.) we can calculate from the given data the value of WD^3V^2/q, the function given in column 4, since this does not involve N and T. Knowing this value we refer to the curves, and read off the value of a function which involves *one only* of the unknowns; in this case, say, $(f)_7$, *i.e.*, V/ND (indicated in column 7), which involves N but not T. Having thus found the value of V/ND, we can, by substituting the known values of V and D, find N. By further reading off from the curves the value of any function containing the other unknown T; for example α (also indicated in column 7), we can again substitute and find T.

[6] $C_n = 15$.

[7] Read as "function four."

[8] Nos. 1 and 2, Fig. 6.

[9] For positive speeds of advance, which are those usually dealt with, these curves are very easily calculated and plotted.

TABLE I.

Number of Case.	Unknowns to be determined.	Derivation of functions given in column 4.	Additional equations derived from equations (1), (2) and (3) (as indicated in column 3) which do not involve the unknowns to be determined (as given in column 2).		Number of the equation.	To find the unknowns given in column 8, solve the equations whose numbers are given in column 7.	
1	2	3	4	5	6	7	8
I.	N & q	γ	$V\sqrt{\frac{WD^2}{T}}$	$=\gamma$	(3)	(1) (2)	N q
II.	q & V	α	$N\sqrt{\frac{WD^4}{T}}$	$=\alpha$	(1)	(2) (3)	q V
III.	N & V	β	$\frac{q}{TD}$	$=\beta$	(2)	(1) (3)	N V
IV.	N & T	γ^2/β	$\frac{WD^3V^2}{q}$	$=(f)_4$	(4)	(7) (2)	N T
V.	N & W	β	$\frac{q}{TD}$	$=\beta$	—	(7) (3)	N W
VI.	N & D	$\beta\gamma$	$\frac{qV}{T}\sqrt{\frac{W}{T}}$	$=(f)_6$	(6)	(15) (2)	N D
VII.	q & T	γ/α	$\frac{V}{ND}$	$=(f)_7$	(7)	(4) (1)	q T
VIII.	q & W	γ/α	$\frac{V}{ND}$	$=(f)_7$	—	(2) (1)	q W
IX.	q & D	γ^2/α	$\frac{V^2}{N}\sqrt{\frac{W}{T}}$	$=(f)_9$	(9)	(15) (7)	q D
X.	V & T	α^2/β	$\frac{N^2D^5W}{q}$	$=(f)_{10}$	(10)	(7) (1)	V T
XI.	V & W	β	$\frac{q}{TD}$	$=\beta$	—	(7) (1)	V W
XII.	V & D	$\beta^2\alpha$	$\frac{q^2N}{T^2}\sqrt{\frac{W}{T}}$	$=(f)_{12}$	(12)	(6) (2)	V D
XIII.	T & W	γ/α	$\frac{V}{ND}$	$=(f)_7$	—	(2) (4)	T W
XIV.	T & D	$\gamma^5/\alpha^3\beta$	$\frac{V^5W}{qN^3}$	$=(f)_{14}$	(14)	(15) (7)	T D
XV.	W & D	$\gamma/\alpha\beta$	$\frac{TV}{qN}$	$=(f)_{15}$	(15)	(6) (2)	W D

Similarly for any other pair of unknowns.

It will be seen that curve 10 in Fig. 7, which expresses the relation between TV/qN and V, corresponds to the efficiency curve, the efficiency of a propeller being $\frac{TV}{2\pi qN}$.

It is interesting to note that when the speed of advance is negative there are two points at which a propeller may have a positive efficiency equal to infinity!

In order to show infinity on the diagrams, and to plot very large and very small values on the same curves, the vertical ordinates have been made proportional to the tangents of angles which increase uniformly. This convenient device, which is possibly new in curve plotting, is due to Mr. F. Gray.

The "loops" shown on the various curves could have been avoided had the ordinates been plotted against α instead of against γ. It is, however, more convenient for many reasons to have the variables plotted against γ, which is proportional to the velocity of advance when W, D and T are constant.

The Horse-Power Curve corresponding to Figs. 4 and 5 is shown in Fig. 8.

It should be noted that the method which is illustrated in Figs. 6 and 7 and Table I. is of quite general application, and that there are many other cases than the design of propellers to which it may usefully be applied.

II.—An Experimental Investigation as to the Relation between the "Thrust Ratio" of Lifting Screws and the Number, Arrangement, Shape and Section of their Blades

The reaction caused by a Lifting Screw rotating in a fluid which has no motion except that which is imparted to it by the screw is obviously a function of the sternward velocity of the fluid at the minimum cross sectional area of the slip stream.

An examination of the streamline flow through a stationary propeller by means of smoke filaments (see Fig. 9) shows that the minimum diameter of the slip stream is about 0.8 of the blade diameter.

In this figure, D represents the diameter of the propeller, and D_1 the smallest diameter of the slip stream.

The smoke filaments show that in the case of a propeller of the usual pitch ratio having thin blades of good aerofoil section, the rotation of the fluid set up is small.

Let us assume, therefore, in the case of the ideal stationary propeller, whose calculated performance is to be our standard of excellence, that no rotation at all is set up, that no eddies are produced, and that the velocity at the smallest diameter of the slip stream is uniform over the whole cross section, and parallel to the axis of rotation; so that the whole of the energy expended in driving the propeller will appear as kinetic energy in the slip stream.

Let A = disk area of propeller in sq. ft.
V = mean of the sternward components of the velocity across the propeller disk area.
V_1 = the sternward velocity at the smallest diameter of the slip stream.
W = weight in lb. of one cubic foot of the fluid in which the propeller rotates.
T = calculated thrust of the ideal stationary propeller in lb.
T_A = actual thrust of the model propeller in lb.
n = revs. per second.
Q = torque in lb.-ft.
g = acceleration due to gravity in feet per sec.
τ = thrust ratio, defined below.
H.P. = horse-power.

The thrust of the propeller

$$= T = \frac{WAV}{g} \cdot V_1 \quad . \quad . \quad . \quad (16)$$

The work done per second on the fluid by the propeller

$$= TV = \frac{WAV^2}{g} \cdot V_1 \quad . \quad . \quad . \quad (17)$$

The kinetic energy in the slip stream

$$= \tfrac{1}{2} \cdot \frac{WAV}{g} \cdot V_1^2 \quad . \quad . \quad . \quad (18)$$

Equating (17) and (18) we obtain

$$V_1 = 2V \quad . \quad . \quad . \quad . \quad (19)$$

Substituting (19) in (16), we have

$$T = \frac{WAV \cdot 2V}{g} = \frac{2WAV^2}{g} \quad . \quad . \quad . \quad (20)$$

But

$$TV = 2\pi nQ \quad \therefore V = \frac{2\pi nQ}{T} \quad . \quad . \quad . \quad (21)$$

(21) in (20) gives

$$T = 2\left(\frac{WA\pi^2 n^2 Q^2}{g}\right)^{\frac{1}{3}} \quad . \quad . \quad . \quad (22)$$

Equation (22) enables us to calculate the thrust of our ideal stationary propeller.

The Thrust Ratio, τ, is defined as the ratio of the actual thrust (obtained from a propeller of disk area A driven at n revs. per second by torque Q in a medium of density W) to the theoretical thrust as calculated by (22).

We have, therefore,

$$T_A = \tau T = \tau \cdot 2\left(\frac{WA\pi^2 n^2 Q^2}{g}\right)^{\frac{1}{3}} \quad . \quad . \quad (23)$$

$$= \tau \frac{2WA}{g} (550)^2 \left(\frac{H.P.}{T}\right)^2 \quad . \quad . \quad (24)$$

$$\text{since } H.P. = \frac{2\pi nQ}{550} \quad . \quad . \quad . \quad (25)$$

Figs. 13 and 14 show how the value of τ is affected by:—

(*a*) the number of blades;
(*b*) the blade section (B.S.);
(*c*) the developed blade outline (B.O.);
(*d*) the developed edge elevation of the blade (B.E.);
(*e*) the designed pitch; or
(*f*) the angle θ[10] between the chord of the aerofoil section and the plane of rotation of the propeller, the pressure face of the blade being perfectly flat.

Figs. 10, 11 and 12 show respectively the blade sections, the developed blade outlines and the developed edge elevations used.

The apparatus on which the propellers were tested was that illustrated in Fig. 2, except that the propellers were rotated in an open tank and not in a bell-mouth.

The propellers were constructed as described in the previous paper, and, so easy did this method of construction prove, that it was found possible to make all the propellers, and carry out the whole of the tests referred to in this paper within three weeks.

Each propeller was rotated at such a speed as to cause it to give a thrust of 0.32 lb. The value of τ was then calculated from the observed torque and revolutions.

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[10] For the propellers used 9in. pitch is approximately equivalent to a value of θ of 30 deg., 6in. to 21.5 deg., 4.5in. to 16 deg., 3in. to 11 deg. and 1½in. to 5.5 deg.

On reference to equation (23), it will be seen that τ is a mere number, so that the experimental values given in Figs. 13-16 should hold for similar propellers of any size working in fluid media of any density.

Actually, however, owing to the fact that the forces are not strictly proportional to areas, densities and squares of velocities, the value of τ for a given propeller varies slightly with the rate of rotation.

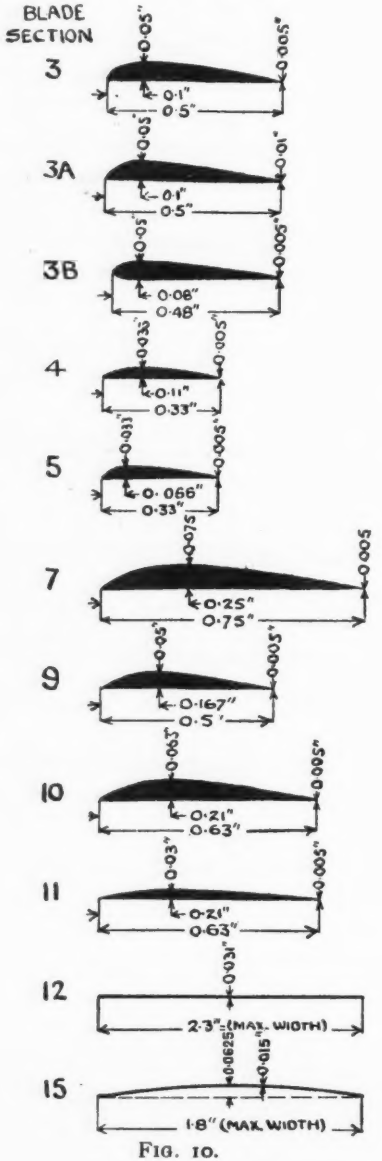


FIG. 10.

The values of τ given in these figures can therefore only be applied with accuracy to any similar propeller for one particular speed of rotation. Since the "corresponding" speeds of rotation are very low when applied to full-sized propellers, the main value of the investigation is to show how modifications in the design of the propeller modify the value of T. See Appendix II.

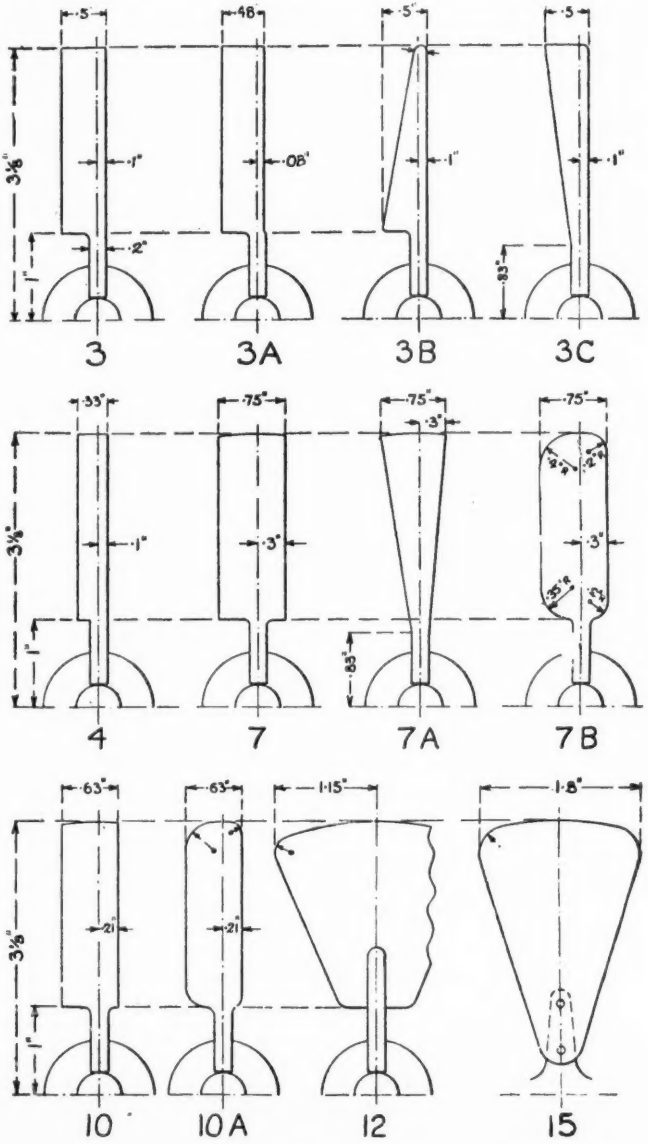


FIG. 11.

Referring now to Figs. 13 and 14.

Cases 1 to 6, and 14 and 15, and 27 and 28 show the disadvantage of having too many blades when the pitch is fine. They also show that the value of τ is only very slightly increased by using blades of helical form.

Cases 7 to 11 show generally the same effects, but with markedly less values of τ when the number of blades is small. This is probably because blade section

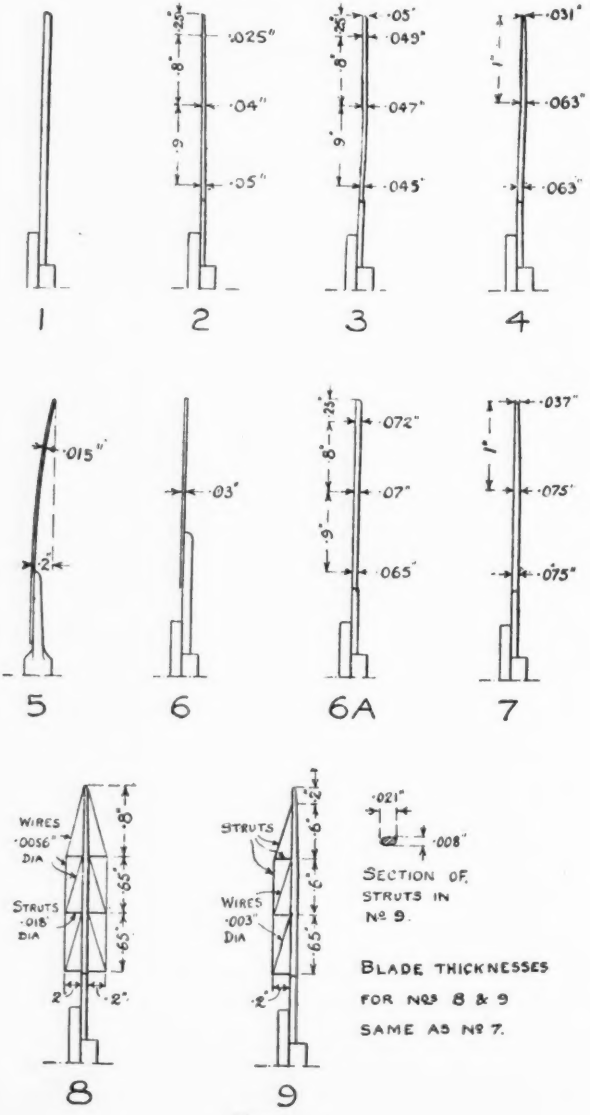


FIG. 12.

3 is not so good as blade section 9, its maximum ordinate being much nearer to the leading edge.

Cases 12 and 13 show the fall in the value of τ consequent upon the thickening of the trailing edge.

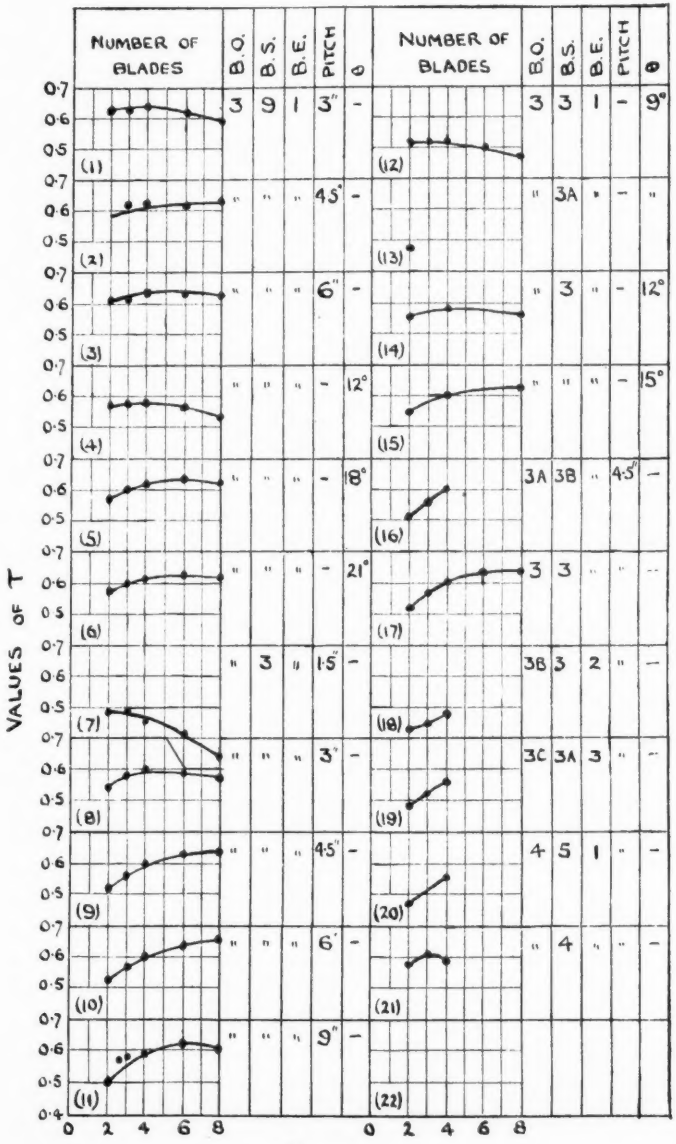


FIG. 13.

Case 16 shows an unexpectedly small diminution in the value of τ consequent upon the rounding off of the leading edge of the aerofoil section as shown at 3B.

Case 18 shows the great reduction in τ consequent upon cutting down the blade outline from 3 to 3A and modifying the edge elevation from 1 to 2.

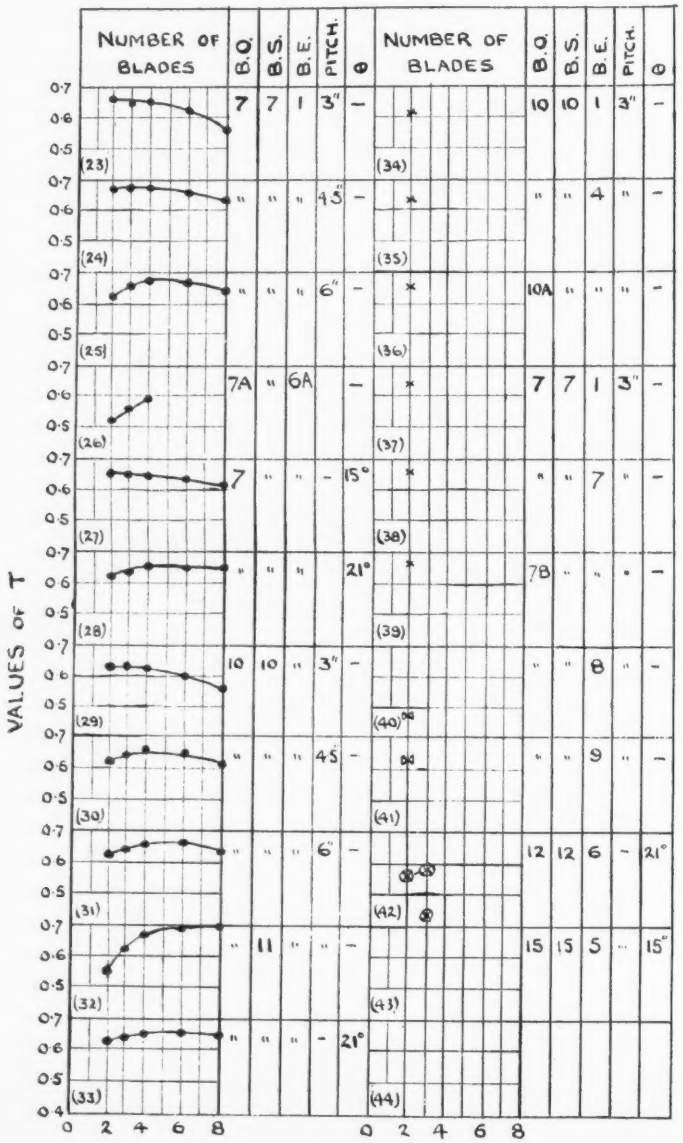


FIG. 14.

Case 19 shows that the modification of blade outline indicated at 3c is also disadvantageous.

Cases 20 and 21 show the importance of good aerofoil section; in Case 21 the maximum ordinate is one-third of the chord length from the leading edge, as against one-fifth in Case 20.

Cases 21 and 24 show how little is to be gained by increasing the blade width for aerofoils of similar section.

Case 26 again shows the disadvantage of cutting down the blade outline.

Cases 31 and 32 show the great advantage to be gained by making the blade thin.

Cases 34, 35 and 36 show the advantage to be gained by thinning down the tip of the blade, and also that it is of no disadvantage to round it off.

Cases 37, 38 and 39 also show the same effect, the value of τ being slightly higher in 39 than in 36, owing to the greater width of blade used.

Case 40 shows the great reduction in τ caused by adding *round* struts and wires to the propeller shown in Case 39.

Case 41 shows that high values of τ are quite possible in the case of propellers strengthened by struts, provided that these are made of streamline form.

Case 43 illustrates a fact well known to those who experiment with model propellers; namely, that the best results can be obtained from blades bent up out of thin sheet metal.

This fact does not, however, materially assist the designer of lifting propellers, as he must necessarily use blade sections of considerable thickness in order to enclose his longitudinal spars.

The broad conclusions from these tests, which were carried out with the object of obtaining data for the design of lifting propellers of large size, would seem to be that there is little advantage (except reduction of vibration) to be gained by constructing such propellers with more than two blades, or by making the blades helical instead of flat (if the blades are made flat, the longitudinal spars are much simpler). It would also appear to be quite practicable to use blades of thin aerofoil section stiffened up by exposed struts and wires of streamline form. It is also advantageous to thin down the blades at the tip and along the trailing edge. So far as the experiments show, there seems to be but little to be gained by departing from blades of rectangular blade outline.

The value of τ for what may be termed "biplane" propellers was also investigated.

The results are shown in Fig. 15,[11] which is self-explanatory.

Higher values of τ might have been obtained by putting the "planes" considerably further apart. But this would have been inadmissible in practice for constructional reasons.

The percentage change of thrust and the variation in the value of τ due to feathering the blades while keeping the speed of rotation constant is shown in Fig. 16.

This point was investigated in order to obtain some idea as to one of the alternatives to using gearing between the engines and propellers.

In the case illustrated in Fig. 16, the pressure face of the blades was made truly helical in shape, and the blades feathered bodily from the boss.

A reference to the streamline diagram, Fig. 9, will show that it is preferable to place the motor or any other necessary obstruction to the flow on the *intake* side of the lifting screw so as to avoid undue loss of energy by friction in the high velocity slip stream.

This point seems to be well understood by those who design electric fans and screw-propelled ships. It is, however, of far less importance in the case of an aeroplane propeller, owing to the high velocity of the aeroplane.

[11] The direction of rotation of all the propellers shown in this figure was contra-clockwise.

The same diagram also shows how necessary it is to " shroud " a circulating fan, such as a radiator fan, which is required to produce a high velocity on the intake side.

The values of τ given in this paper were determined with the propeller 11 in. below the water level in an open tank 20 ft. square; preliminary tests having shown that the value of τ was unaffected even when the depth was much less than this.

It is interesting to note that when the depth of immersion was only 1 or 2 in., or when large flat surfaces were caused to obstruct the flow on the intake or the discharge side of the propeller, that the value of τ increased by 12 to 15 per cent.

The author regrets that the very limited time available under present conditions has prevented reference to the more interesting objects of the investigation, of which these papers form but a bare and uninteresting summary.

He also regrets that for the same reason it has been found impossible to present a third paper dealing with the effect on the value of τ of side currents impinging at various angles to the plane of rotation of the propeller.

He desires, in conclusion, to thank his firm, Messrs. Geo. Kent, Ltd., of Luton, at whose works the tests were made, and also Mr. F. Gray, Mr. N. H. Hunt and Mr. W. N. Bond, who have assisted him in the experimental work and in the preparation of the paper.

Appendix I.

The dimensional equations show that if viscosity is taken into account, and the conditions are not further complicated by cavitation in the case of water tests, or the compressibility of the fluid in the case of air tests, " corresponding " speeds are obtained when

$$\frac{V d W}{\mu} = \text{constant} \qquad . \qquad . \qquad . \qquad (26)$$

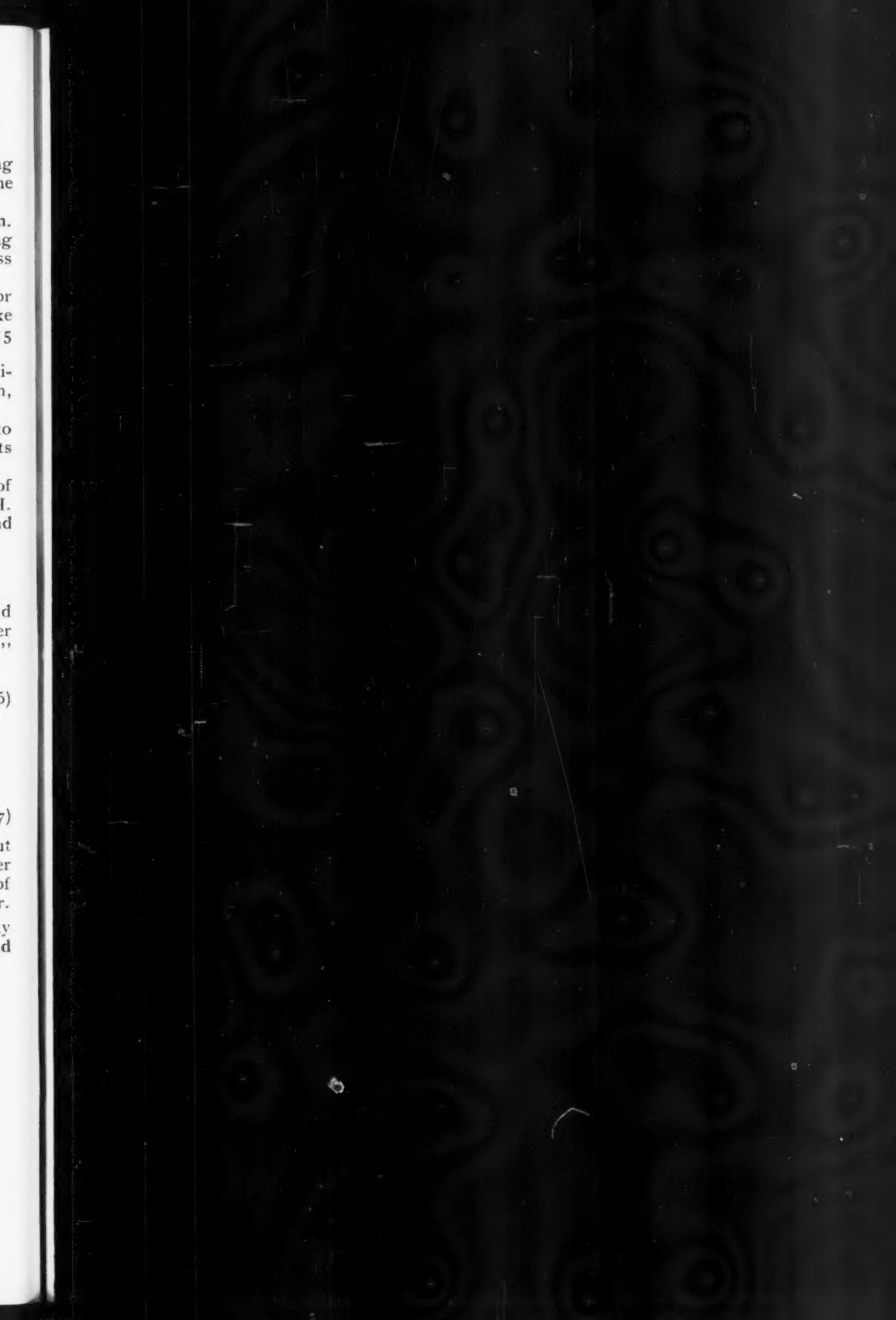
where μ is the coefficient of viscosity.

Since, in the case of propellers,

$$V \propto N d,$$

" corresponding " speeds are obtained when

$$\frac{N d^2 W}{\mu} = \text{constant} \qquad . \qquad . \qquad . \qquad (27)$$

The average speed of the model propellers during the tests was about 200 revs. per minute, so that the " corresponding " speed for an 8 ft. propeller is only about 0.8 revs. per minute, while 30,000 revs. per minute is the speed of the model which " corresponds " to 1,200 revs. per minute of the 8 ft. propeller.

It is thus, unfortunately, impossible to apply the $V d W/\mu$ criterion with any useful result to these tests. For this reason the actual revolutions, torque and thrust for each experimental point have not been given in the paper.